NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Australian Sheep Industry CRC: Economic Evaluations of Scientific Research Programs

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Abstract: By the end of its seven-year term in 2007-08, the Australian Sheep Industry CRC (Sheep CRC) will have received total funds of about $90 million, that comprises Commonwealth and industry funding of $30 million, and in-kind contributions valued at $60 million. This level of public and private funding emphasises the need for the Sheep CRC to demonstrate that its research programs will generate sound economic returns to all stakeholders. This paper reports an evaluation of the potential economic value of the achievements of the Sheep CRC at the midpoint of its term of operations at which it has some completed research and a large volume of research in progress. The main question that has been addressed in this evaluation concerns the nature and likely magnitude of the potential benefits relative to the costs of their realisation. The economic methods and other procedures that were used to answer this question, the evaluation scenarios and the results obtained are described. Based on the defined *with*- and *without*-Sheep CRC evaluation scenarios, the 'bottom-line' result was that the Sheep CRC's scientific research programs have the potential to deliver a total incremental benefit with a 20-year net present value (NPV) of $191.3 million, and a total benefit-cost ratio (BCR) of 8.1:1 (both at a 5% real rate of discount), indicating that the Sheep CRC's total research investment over all programs has the potential to return about $8 for every $1 of research investment funds.

Keywords: sheep research; economic evaluations; economic-surplus- benefit-cost analysis.

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Acronyms and Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
AG	Actual productivity growth
ARC	Australian Research Council
ASGD	Australian Sheep Genetic Database
AWI	Australian Wool Innovation
BCA	Benefit-cost analysis
BCR	Benefit-cost ratio, defined as the ratio of discounted benefits to discounted costs
Beef CRC	Cooperative Research Centre for Cattle and Beef Quality
CDF	Cumulative distribution function
Consumer surplus	A measure of economic welfare change affecting consumers, defined as the area below the demand curve and above the price line
DREAM	**D**ynamic **R**esearch **E**valu**A**tion for **M**anagement model
EDM	Equilibrium displacement model
Elasticity (price)	An economic measure of supply or demand response to a price change, defined as the percentage change in quantity supplied or demanded for a one per cent change in price
IAM	Individual animal management
MLA	Meat and Livestock Australia
NPV	Net present value, defined as the difference between discounted benefits and discounted costs
OFFM	On-farm fibre measurement
PFP	Partial factor productivity
PG	Potential productivity growth
Producer surplus	A measure of economic welfare change affecting producers, defined as the area above the supply curve and below the price line
R&D	Research and development
Rendell-McGuckian	A spreadsheet model used by the Sheep CRC for project monitoring
RPG	Rate of productivity growth
Sheep CRC	Australian Sheep Industry Cooperative Research Centre
TFP	Total factor productivity

Executive Summary

The Australian Sheep Industry Cooperative Research Centre (Sheep CRC) commenced operations in 2002 and will receive Commonwealth and industry funding totalling about $30 million over its seven-year period, as well as in-kind contributions from core and supporting parties with an approximate value of $60 million. The Sheep CRC's main objective is to develop new technologies, management practices and marketing strategies that will make the sheep industry more profitable and sheep products more highly valued by consumers. An important measure that the Commonwealth government will use to judge the Sheep CRC's ultimate success will be that it has generated a sound economic return to all stakeholders from its public funding. The estimation of those potential returns has been the principal objective of Sheep CRC Project 3.3.2, with a particular emphasis on the science Program 1 (Strategic Research) and Program 2 (Improving Profitability in the Sheep Industry).

The purpose of the economic evaluations reported in this paper was to determine the potential benefits of the Sheep CRC's scientific research to the Australian sheep industry. This purpose has necessitated the development and application of a robust integrated economic modelling system that would enable the Sheep CRC's research to be evaluated in terms of its potential impacts on the producers and consumers of sheep products. An emphasis was to demonstrate that improved technologies in sheep production and product development can benefit not only producers but also the consumers of sheep products whose taxes provide the bulk of funding to public research agencies. It is this type of economic information that is required by the Sheep CRC to demonstrate that its research investments have delivered properly measured economic benefits to Australian taxpayers and industry stakeholders.

The research investments made by the Sheep CRC were considered to be part of a long history of research and development in the Australian sheep industries. It was expected that most of the areas of research involved in the science programs would have continued to be undertaken in the absence of the Sheep CRC, but at a lower level of funding and over longer periods. It was considered that the main effect of the Sheep CRC's research was to increase the scale and intensity of research and to expedite the delivery of new technologies to the sheep industry through the provision of additional research funding and by reinforcing the collaborative links that exist between Australian sheep research institutions. The research evaluation task was therefore to measure the incremental or marginal benefits that could be legitimately attributed to the Sheep CRC through the definition of realistic *with*- and *without*-research scenarios. These incremental or marginal benefits were estimated as the differences in the benefit levels that could result under *with*- and *without*-research scenarios.

The evaluations were undertaken in two broad stages in an *ex ante* benefit-cost context in which the program costs were known and the benefits were estimates of the expected future returns. In the first stage, the six main research areas in the science Programs 1 and 2, which share about 80 per cent of the Sheep CRC's budget, were separately evaluated using a 'top-down' research evaluation method following the recommendations of the Allen Consulting Group (2003). This method relies on being able to identify a potential for productivity growth in the Australian sheep industry, compare that potential with formallymeasured rates of actual productivity growth in the industry and identify the potential for the Sheep CRC to enhance that growth. Benefits were not estimated for Programs 3 (Implementing Innovation), 4 (Education and Training) and 5 (Administration) whose costs were treated as being underlying costs of the Sheep CRC's research, although it was recognised that these programs had the potential to deliver significant long-term economic benefits to the sheep industry and Australian taxpayers. These additional benefits mainly related to capacity building and education and training.

In the second stage, a project selected by the program leaders from each of the five sub-programs in Program 1 and one project from Program 2 were evaluated using a 'bottom-up' method to provide specific estimates of the potential returns to those project areas.

The programs and projects that were evaluated and the procedures and data required to undertake the evaluations (and their sources) are detailed in Sections 2 and 4 of this paper. In both evaluations, important input data for the economic modelling such as productivity growth estimates, technology adoption levels and lags, and production cost differences were derived from a consensus data approach involving the program leaders and the industry advisory panel, as well as from spreadsheet modelling undertaken independently by the Sheep CRC's management.
Under both evaluation methods, the incremental benefits to the Sheep CRC's research programs and projects were estimated using partial equilibrium measures of economic welfare changes that result from new technology adoption in primary industries. Both the program and project benefits were estimated using a regionally-disaggregated economic surplus model that was also stochastically simulated for the project evaluations. The estimated benefits were matched against the full research costs to calculate the net present values (NPVs) and benefit-cost ratios (BCRs) over a 20-year period at a 5 per cent real discount rate.

The results are presented in four parts.

- Part 1 gives separate benefit-cost estimates for the six programs for both the *with*- and *without*-Sheep CRC scenarios. This part of the evaluation used a 'top-down' method and input data that were derived from both program managers and management's spreadsheet modelling (using the Rendell-McGuckian model) that was undertaken independently of this evaluation.

- Part 2 gives the net benefit-cost estimates for the six programs (derived from the 'top-down' analysis in Part 1) that were held to be the 'bottom line' or the net results of the evaluations. These are the potential benefits that could be attributed to the Sheep CRC's research investment, both by program area impact and in aggregate over all programs.

- Part 3 gives a regional disaggregation of the program level results to indicate the shares of the net benefits that could flow to all participants in the Australian and foreign sheep industries. This analysis indicated the likely distribution of the net benefits of the potential widespread impacts of the Sheep CRC's research.

- Part 4 gives the benefit-cost estimates of six selected projects from Programs 1 and 2 that were evaluated using a 'bottom-up' method. This part of the evaluation also used input data for individual projects obtained from the program leaders and from the management's Rendell-McGuckian modelling.

The results given in Parts 1, 2 and 3 were all derived from the 'top-down' analysis. In the Part 1 results, estimates of the potential benefits to each research program by area of industry impact under the *with*-Sheep CRC scenario have NPVs that range from $72.2 million for genetics research that improves the supply of wool, to $1.7 million from research that impacts on sheepmeat supply under wool science research. The range of the BCRs is from 17.5:1 for research into parasite management that impacts on wool demand to 1.6:1 for nutritional research that affects the supply of sheepmeats over the 20-year period of the benefit-cost simulation. All areas of research generate positive NPVs and BCRs that are greater than unity. All programs therefore have the potential to deliver significant long-term economic benefits to the Australian sheep industry.

A similar set of results was generated for the hypothetical *without*-Sheep CRC scenario. The Part 2 results indicate the incremental benefits to each of the Sheep CRC's programs that are net of the benefits that could result from an alternate program of research under the *without*-Sheep CRC scenario. The total incremental benefit has a NPV of $191.3 million which is the value of the total discounted benefits that could be attributed to the Sheep CRC's research investment in the six program areas. The BCR of 8.1:1 indicates that the Sheep CRC's total research investment over all programs has the potential to return about $8 for every $1 invested. The main contributors to this total incremental benefit are genetics research that affects the supply of wool ($49.9 million), improved parasite management in wool production ($35.1 million), and research that impacts on sheepmeat production ($27.1 million). This benefit results from the differences in the expected impacts of the program research areas on productivity growth in the sheep industry, from the differences in the expected adoption profiles for the programs' technologies, and from differences in the costs of research under the two scenarios.

In Part 3, the total incremental benefit was then disaggregated to indicate the relative benefit shares between sheep commodity producers and consumers in Australia and in international markets. Australian sheep producers gained about 75 per cent of the total net benefit because they could directly access the new technologies. Sheep product consumers in all regions gained from lower product prices that followed supply increases, while sheep producers in the four international regions lost economic surplus valued at $113.6 million from price spillovers because they could not adopt the cost-saving technologies.

The results in Part 4 were derived from the 'bottom-up' analysis. These are the stochastic 20-year benefit-cost analyses of the six selected projects from Programs 1 and 2. Again, these are incremental benefits that are the simulated differences between the *with*- and *without*-Sheep CRC scenarios over the range of probability distributions that were defined for the adoption variables. The median NPVs of these benefits were between $15.8 million for Project 1.1.1 (Genetic Analysis of Sheep Production Traits) to $68.5 million for Project 2.3.1 (On-farm Implementation Trials), and the incremental BCRs range from 3.4:1 for Project 1.1.1 to 22.5:1 for Project 1.4.5 (On-line Sheep Worm Management). The minimums and maximums show the spread in the values of the benefit-cost criteria while the medians indicate the most likely benefit-cost outcomes for the projects. Cumulative distribution functions of the simulated benefit-cost results were calculated to determine the probabilities of the projects delivering a particular benefit-cost outcome. These functions indicated that there was zero probability that any of the projects that were evaluated would deliver a negative incremental return. The values in the median 50th percentile (or the mid-points of the probability distributions) were the most likely benefit-cost outcomes for the projects, i.e. where there is at least a 50 per cent probability of obtaining that result. Differences in the benefit-cost estimates between the projects resulted from differences in project costs and in the impact of the technologies on production costs and product yields.

The main conclusion from the evaluations of the two science programs and the sample of projects is that the Sheep CRC could generate large economic returns to the Australian sheep industry on its research investment. These benefits have been estimated to result from an increase in sheep industry productivity that is expected to come from the Sheep CRC's activities, and from faster rates of and higher levels of technology adoption.

The sheep industry has historically had low rates of productivity growth relative to other agricultural industries. Investment in research and development provides the main opportunity to improve this rate of growth. Industry productivity is improved when the adoption of a new production technology enables producers to lower unit production costs and consumers to access increased commodity supplies at lower cost. The Sheep CRC's complementary investment in extension and communication provides the main mechanism for increasing the level of new technology adoption in the sheep industry. As indicated in Section 4, investment in extension to encourage technology adoption is the major practical way that the rate of productivity growth can be increased.

Several comments and qualifications were made on the overall results of these evaluations. It was recognised that some of the benefit estimates were unlikely to match prior expectations. Where that has occurred, it is most likely due to the relatively low adoption expectations for most of the programs' technologies that were derived from the independent spreadsheet modelling done by the program leaders and management. While these low values for the adoption variables were consistent with the findings of published studies of technology adoption in the Australian sheep industry, it was considered that the Sheep CRC has played an important role in extension and education that could be expected to improve the overall level of technology adoption in the industry over time.

A further factor is the high costs of the programs and the values of the in-kind contributions in particular, where these costs were large relative to Sheep CRC grants. In-kind costs were at least 84 per cent of the first-year total costs of each program and at least 60 per cent of the total program costs in the first three years. Such a cost pattern has important implications for the discounted cash flows, where high initial costs weight the results much more heavily than the offsetting program benefits that only start after a lag of several years. It was also recognised that the definitions of the *with*- and *without*-Sheep CRC scenarios implied that there was likely to be comparable levels of research that would eventually be undertaken in the areas represented by the Sheep CRC's programs but that would require longer periods for initiation and completion. This presumption appears to be reasonable in the traditional areas of Australian sheep industry research, but less so in other program areas such as individual animal management that can be claimed to be major innovations of the Sheep CRC. Higher benefits would result to those programs from the larger differences in the anticipated levels of adoption for those technologies, and in the times taken for them to be realised.

1. Introduction

The Australian Sheep Industry Cooperative Research Centre (Sheep CRC) is an agricultural research agency that comprises universities, governments and private industry. The Sheep CRC commenced operations in early 2002 and will receive Commonwealth funding totalling $19.8 million over its seven-year grant period. The Australian sheep industry has also agreed to invest about $10 million in the Sheep CRC over this period, while core and supporting parties will have made in-kind contributions to a value of about $60 million. The principal objective of the Sheep CRC is to develop new technologies, management practices and marketing strategies that will make the sheep industry more profitable and sheep products more highly valued by consumers. The attainment of that objective has necessitated the development of ‘outcomes that will increase the rate of productivity gain and ensure that the sheep industry is able to meet community expectations for animal welfare, resource use and product safety’ (Sheep CRC Annual Report 2003-04).

Australia’s rural industries are faced with the need to make substantial long-term productivity gains that will enable them to better meet increasingly more complex economic, social and environmental expectations. New technology development is an important source of economic growth in these industries. Producers benefit from new technology adoption through productivity improvements and consumers benefit from lower prices when technologies that are widely adopted in competitive industries lead to higher levels of production (Griffith *et al.* 1995). Technology development in Australian agriculture continues to attract a high level of public funding relative to other countries because there have typically been inadequate profit incentives for the private sector to invest in this activity to a socially-desirable level (Brennan and Mullen 2002). The level of public and private or industry funding allocated to the Sheep CRC has brought with it the requirement to demonstrate that this investment will ultimately enhance the welfare of both the national economy and the sheep industry. For both funding sources, this requirement recognises that the investment in sheep research has an opportunity cost equal to the expected benefits from investment in other areas in the economy and in the sheep industry.

Mullen (2004) noted that the formal economic evaluation of agricultural research funded from public and industry sources served several purposes. The main purpose, as touched on above, is the external requirement for accountability in the way the research agency has used the resources it has been responsible for. A second purpose is that the evaluation process can be used within the agency to assist in allocating resources to areas that are likely to have high payoffs and to assist in designing research and extension projects that have objectives that are clearly defined and are consistent with the role of a public research agency. A third purpose is that working through a formal economic evaluation framework enables the research staff involved to better appreciate the means by which, and the extent to which, research and extension activities are likely to impact at the farm and industry levels. The outcome should be better designed and managed projects. Part of this evaluation process is to identify the extent to which the market is failing to deliver the research outcomes that are sought by the industry or by the public. These purposes are highly relevant to the Sheep CRC evaluations that are reported in this paper.

The main issues in a research evaluation process are to qualitatively describe the potential economic and social impacts of the program, to consider the rationale for public investment in that research from a market failure viewpoint which seeks to identify if producers are under-investing in research and to examine the share of public and private funding in the research investment, and to assess whether the benefits flow largely to producers or to the public. An additional issue is to attempt to quantify as many impacts as possible to arrive at the common measures of economic performance; net present values, internal rates of return and benefit-cost ratios (Mullen 2004). An important part of this process is to identify both the expected impact on an industry of the research investment in the development of a particular technology (the *with-research* scenario) and whether the industry would continue to develop such technologies without the specific research investment being studied (the *without-research* scenario). It is rare that the *without-research* scenario represents a no-change future because there is usually other research into similar technologies that will generate ongoing productivity growth in the industry. This quantitative evaluation process also indicates the relative importance of the variables that determine the levels of benefits from a research program, including the time lags involved in developing the technology and it being adopted in the industry, the expected rate and extent of adoption of the technology, the on-farm impacts and the industry changes in supply and demand.

The Sheep CRC will be regarded as having been successful if its research outcomes deliver economic benefits to all stakeholders that are additional to the benefits from the 'normal' flow of research funds. The Department of Education, Science and Training that oversights Australia's CRC program will judge the Sheep CRC's ultimate success on its ability to deliver such benefits. One of the main assessment criteria the Department will adopt is that the (public) funding the Sheep CRC has received has generated good value for the taxpayer, i.e. there is a sound return on that investment relative to the costs. Accordingly, the Sheep CRC has placed a high priority on the economic evaluation of its research, particularly in relation to the production technology and product improvement programs.

The principal objective of Sheep CRC Project 3.3.2 (Economic Analyses of Sheep CRC Activities) has been to address that requirement through the economic evaluation of the expected returns to the Australian sheep industry from the Sheep CRC's investments in new technologies over its seven-year funding term. This has required the development of a robust economic modelling system to enable the Sheep CRC's scientific research in six major program areas to be evaluated in terms of their potential impacts on the producers and consumers of sheep products. An emphasis in this evaluation process has been to demonstrate that the development and adoption of new technologies in sheep production and product development can benefit not only sheep producers, but also wool and sheepmeat consumers who through their taxes, provide the bulk of the funding to public research agencies such as the Sheep CRC. This type of economic information is required by the Sheep CRC to demonstrate that its research activities have delivered properly measured economic benefits to Australian taxpayers and other funding stakeholders.

This report provides an analysis of the potential economic value of the achievements of the Sheep CRC at the midpoint of its term of operations. At this point, the Sheep CRC has completed its research with noteworthy achievements in some areas and has a considerable volume of work-in-progress in others. Using robust economic methods, and consistent with a similar economic evaluation of the CRC for Weed Management Systems (CIE 2001a), the critical question that has been addressed in this evaluation relates to the nature and likely magnitude of the potential benefits relative to the costs of their realisation. The answers to these questions are essential components of the Sheep CRC's process of accountability for the public funds it has invested. These answers also provide guidelines to the relative returns to different areas of sheep research. This should enable the assessment of how expenditure in any proposed extension of the Sheep CRC might be rationalised to enhance its returns to the community. The issues and methods adopted to evaluate the Sheep CRC scientific research programs are described in the following sections of this paper.

2. The Sheep CRC's Scientific Research Programs

The Sheep CRC provides collective industry benefits through the generation of knowledge that improves industry performance under the constraints of global competition and consumer demands for increased quality. Research outputs are delivered through public-private research partnerships that have a strong focus on the improvement of industry performance (Howard Partners 2003). This type of CRC comprises about two-thirds of all the CRCs that have been funded in Australia since 1993.

Consistent with this definition, the Sheep CRC was organised around a suite of research programs that relate to most aspects of Australian sheep production, marketing and technology transfer. These activities vary between new research in areas that have previously received little or no attention, to expediting other research that was being developed before the advent of the Sheep CRC**.** Two production research programs focussed on genetic technologies, wool science, meat science, parasite management and strategic nutrition (Program 1), and on the development of electronic identification technologies to enable sheep management on an individual animal basis rather than on a flock basis (Program 2). Research undertaken under Program 1 was expected to provide the basis for promoting the more intensive animal management according to individual merit being investigated in Program 2. Program 3 concerned communication, extension, economic evaluation and knowledge management, while Program 4 concerned education and training at university and industry levels.

The Sheep CRC's Strategic Plan state that its main objectives were to develop a range of technologies, practices and delivery mechanisms that would provide measurable gains in sheep industry productivity and profitability.

The research outcomes were also expected to meet community and stakeholder expectations regarding animal welfare, resource use and product safety (these benefits were not valued). That has involved the development of new technologies, management practices and marketing strategies that were expected to make the sheep industry more profitable and sheep products more highly valued by consumers.

Since approximately 80 per cent of the Sheep CRC's budget is allocated to the two production research programs, the potential impact of that research is the main concern of these economic evaluations. All projects that were initially funded in the programs and their status at the time of the evaluations are indicated in Table 2.1.

Table 2.1. Sheep CRC production and product enhancement research programs: status at time of evaluation in 2005[a]

Programs and projects							
SP1.1		**SP1.3**		**SP1.4**		**P2**	
1.1.1	active	1.3.1A	active	1.4.1A	active	2.1.1	completed
1.1.2	completed	1.3.1B	active	1.4.1B	completed	2.1.2	active
1.1.3	completed	1.3.1C	active	1.4.1C	active	2.1.3	completed
1.1.4	completed	1.3.1D	active	1.4.1D	completed	2.2.1	active
1.1.5	active	1.3.2	active	1.4.1E	active	2.2.2	completed
1.1.6	active	1.3.4	active	1.4.2A	completed	2.2.3	completed
		1.3.5	active	1.4.2B	active	2.2.4	completed
SP1.2		1.3.6	active	1.4.4	completed	2.3.1	active

1.2.1	active	1.4.5	active	2.3.2	active
1.2.2	active	1.4.6	active		
1.2.3	completed	1.4.7	active		
1.2.4	completed				
1.2.5	completed	**SP1.5**			
1.2.6	active	1.5.1	active		
1.2.7	active	1.5.2	completed		
		1.5.3	active		
		1.5.4	completed		
		1.5.5	active		

[a] project has been completed and achieved its objectives or was cancelled prior to completion.

Program 1 was delivered through five sub-programs:

- Genetics (Sub-program 1.1; three current projects)
- Wool Science and Production (Sub-program 1.2; four current projects)
- Meat Science (Sub-program 1.3; eight current projects)
- Parasite Management (Sub-program 1.4; seven current projects)
- Strategic Nutrition (Sub-program 1.5; three current projects).

Program 2 had no sub-programs but had nine separate projects, four of which are current:

- Evaluating individual animal management strategies (Project 2.1.2)
- Development and integration of sheep identification (ID) equipment (Project 2.2.1)
- On-farm implementation trials (Project 2.3.1)
- Opportunities for IAM in sheepmeat production (Project 2.3.2)

Sub-Program 1.1: Genetics

Genetic improvement in wool and sheepmeat production is essential to maintaining the viability of the Australian sheep industry. In the long term, the impact of genetic technologies will result from the development of comprehensive genetic evaluation systems that enable animals to be objectively compared for their wool and meat traits and marketed on genetic merit. Lindsay (1998) stated that quantitative genetics had not been as effectively applied in sheep breeding programs as it had been in the other major livestock industries (such as the beef industry) (Farquharson *et al.* 2003, Burrow *et al.* 2003). Genetic progress in sheep breeding should approximate a theoretical maximum since the theory that underlies livestock breeding programs is uniform across the industries. Progress towards that maximum depends on the success of geneticists in developing improved breeding programs that can be implemented by commercial breeders who supply stock to the industry (Lindsay 1998).

Because the science of sheep breeding and genetics is experiencing important developments in the areas of information and reproductive technology and molecular genetics, the Australian sheep industry needed to adopt these technologies where they had been proven to be cost effective. Efficient sheep breeding programs are based on the objective measurement of genetic trait variation, pedigree recording, accurate genetic evaluation and optimal selection decisions. The value of genetic improvement to the sheep industry is largely determined by the rate of genetic gain achieved by ram breeders and how these gains are captured and passed onto commercial producers.

While genetic improvement from selection programs is both permanent and cumulative, the evidence suggests that these benefits have only been partially realised because of relatively low rates of industry adoption of improved genetic-based technologies (Section 3.3). For the Australian Merino industry, Atkins (1993) estimated that the maximum possible gain from genetic improvement was equivalent to $0.40 per dry sheep equivalent per year which translated into a 2.7 per cent improvement in annual gross margin. These benefits were both permanent and cumulative to the point where the entire commercial Merino flock would benefit from genetic improvement within 30 years.

Each of the projects in Sub-program 1.1 attempted to develop more efficient breeding programs that would ensure the rapid achievement of long term genetic improvements in wool and meat production. Accurate knowledge of these aspects and their correlation structure that are essential for optimal genetic improvement were major issues that were investigated in this program. The potential for selection across breeds and environments to be better understood were also investigated. A particular focus of this program was on 'difficult to measure' traits including disease resistance, aspects of wool and meat quality and traits that contribute to the integration of wool and meat production such as reproduction rate and feed efficiency. These traits are more difficult to select for than those that are traditionally selected for such as fleece weight and fibre diameter in Merinos, and carcase characteristics in meat breeds.

Sub-program 1.1 formed part of a national effort initiated by Meat and Livestock Australia (MLA) and Australian Wool Innovation (AWI) to coordinate and improve Australian research capacity in quantitative genetics in the sheep industry. Its objectives were: (a) to determine the quantitative genetic nature of relationships between sheep production traits and to provide the sheep industry with accurate genetic parameters and genetic evaluation models for a comprehensive range of traits for wool and meat production, product quality and resistance to parasites for use in genetic evaluation and optimisation of commercial breeding programs and accurate prediction of their outcomes (Project 1.1.1); (b) to estimate the quantitative genetic relationships between parasite resistance and production across environments, and to demonstrate the economic benefit of breeding for parasite resistance (Project 1.1.2); (c) to collate a DNA/tissue base from valuable resources that can be used for gene mapping studies by the Sheep CRC and others (Project 1.1.3); (d) to identify the molecular genetic basis of wool quality traits and develop genetic markers for resistance to fleece rot for use in marker assisted selection/introgression programs (Project 1.1.4); (e) to clarify the genetics of fibre pigmentation (Project 1.1.5); and (f) to devise optimal strategies to utilise information on major genes in breeding programs and more generally to develop genetic resources optimally (Project 1.1.6).

The research combined phenotypic and DNA data from resource flocks, and from field data. The sub-program collaborated with providers of genetic services that are to be the main mechanism for commercialising the research outcomes. The molecular genetics research was coordinated with the national sheep genomics MLA/AWI consortium.

The Sheep CRC recognised the value of the large volume of data that was available from past genetics research as a starting point to this sub-program. The revised genetic parameters from this research are intended to be incorporated into the parameter matrix for genetic evaluation used in the Australian Sheep Genetic Database (ASGD) which will be available to other providers of genetic evaluation such as Advanced Breeding Services, Select Breeding Services and Lambplan. These collaborative arrangements provide a major mechanism for enabling new genetic technologies to be delivered to the industry through genetic evaluation and related services, as well as providing more accurate genetic evaluations of breeding animals that result in faster genetic improvement from breeding programs. The more effective breeding programs in Merino and maternal ram breeding flocks directly pass on improvement to commercial Merino and crossbred ewe flocks.

Sub-Program 1.2: Wool Science and Production

Major demographic changes in the Australian sheep flock over the past decade have had significant effects on Australian wool production. The national sheep flock has declined to below 100 million which is the lowest sheep population in a century. Matings of Merinos sheep (the basis of the wool industry) to specialist meat breeds have increased, and current farm price relativities that favour meat have led to reduced flock wether proportions and greater numbers of meat breeding ewes. An associated change has been a decline in the production of pure Merino wool and a reduction in its staple strength. There have been heavy price penalties for wool of low staple strength and for the superfine types in particular. Lamb dressed weight prices have risen to record levels at the same time.

The sheep industry faces the challenge of adapting to these changes in ways that mutually benefit producers and processors. Meeting this challenge requires clear communication of the importance of quality issues through the wool pipeline so that new approaches to breeding, management and clip preparation can be developed that will provide benefits to all sectors of the industry. The wool and meat production components of Sub-program 1.2 were initiated to address these issues with an emphasis on improving the information flow and understanding along the production-processing pipeline. Project 1.2.1 was a modelling project that provided an improved insight into the requirements of wool consumers and processors in the various segments of the wool market. This included surveys and predictions of changes in the wool clip that were occurring in response to the changing structure of the sheep flock.
Changes in the composition of the wool clip emphasised the need for more effective use of on-farm fibre measurement (OFFM) to better understand and reduce the problems of low staple strength wool on processing performance, particularly in fine Merino wools where the price discounts are large (see Templeton *et al.* 2004). A major problem for many wool producers is the lack of clear feedback on the fibre characteristics that are important in wool processing and most influence prices (i.e. fibre diameter, staple strength and curvature), and how these factors can be best managed at the production level. Information from auctions, processors and end users of wool has indicated that the price differences for variation in these characteristics may often appear inconsistent with their impacts on processing performance.

Greater use of OFFM would enable producers to better align their wool production with the needs of processors and end users. Project 1.2.2 examined the potential contribution of new and improved OFFM, including the outcomes of an AWI-funded project on prediction of staple strength, to this objective. Other project areas in the wool program section included understanding the interactions between fleece and non-wool components (eg., rain, sunlight, dust and wind) on fibre damage, and determining their effects on dyeing and wool processing performance (Project 1.2.3B), developing tests for recommending procedures and precision limits for wool staple profile measurement and for interpreting staple profile data (Project 1.2.4), and developing improved methods for managing staple profiles and for evaluating the effects of varying shearing intervals on the returns to fine wool production (Project 1.2.5).

Project 1.2.6 concerned the profitability of various systems for producing wool and meat from Merino sheep which comprise about 90 per cent of the national sheep flock. Strong increases in sheepmeat prices have encouraged changes from wool to meat production to the extent that nearly 50 per cent of Merino ewes are now being mated to specialist meat breeds. The widespread use of Merinos means that there are more opportunities for meat and wool production from this breed and more potential enterprise mixes in the various sheep production environments. However, this form of meat production has the challenge of overcoming market discrimination against pure Merino meat products, particularly at the lower carcase weights of and prices for Merino lambs relative to crossbreds. This project sought to provide information on optimal management systems for the joint production of wool and meat from Merinos.

Sub-Program 1.3: Meat Science

This sub-program was a collaborative venture between the Sheep CRC, MLA and various sheepmeat processors, with a focus on investigating the factors that influence production efficiency and consumer demand for lamb and other sheepmeats. Its outcomes addressed three main industry issues: the effects of genetics and nutrition on carcase growth (weight, muscle yield and fat) and the subsequent value of the carcase realised by producers; precision processing including the reduction in loss from dehydration and optimising the effectiveness of electrical stimulation for increasing meat tenderness and improving meat colour; and consumer acceptance of sheepmeats in terms of eating quality, meat colour and odour. The overall issue in these projects was meat quality and the opportunities for management and genetics to interact to produce the consistency in product quality that the market is increasingly demanding.

The research was conducted through three large prime lamb and yearling mutton growth experiments. The first investigated the development of prime lamb progeny from high muscle and high growth Poll Dorset sires that were given moderate and high levels of nutrition. The second generated progeny from Poll Dorset, Border Leicester and Merino sires with a focus on growth and muscle development, while the third was similar in design to the first but used more extreme Poll Dorset sires and targeting strategic growth path effects at time of weaning. Merinos were also a program focus because of the increased use of this breed for meat production.

The main investigations were into muscle and fat biology and the role of nutrition in the expression of genetic potential for growth to aid in the selection of sheep to produce muscle rather than fat (Projects 1.3.1A-D), meat flavour and odour chemistry to improve consumer acceptance (Project 1.3.2) and optimising the eating quality of more highly muscled lambs where changes in the biochemistry and muscle cellularity have the positive effects of more muscle, less fat, greater processing efficiency and better colour (Project 1.3.4). A primary outcome of this part of the sub-program was to understand the factors affecting muscle and fat development (or lean meat yield) in the carcase as this is the basis for payments for prime lamb and yearling mutton. This is particularly the case with mutton which is increasingly being used as prime cuts and in industrial meat products. The extensive differentiation of this product is expected to achieve price stability across the various food market segments.
Project 1.3.5 concerned the sheepmeat processing sector through investigations into new generation electrical technologies for managing the pH/temperature window post slaughter to optimise meat tenderness for various market requirements. This project involved 12 processors in New South Wales, Victoria and Western Australia collaborating with the Sheep CRC to optimise the use of electrical stimulation to improve meat tenderness without increasing drip loss or reducing colour stability. Practical and simple methods for assessing dehydration in slaughter animals were developed and strategies for increasing the

dehydration status and lean meat yield of slaughter animals were investigated. The value of reducing dehydration in carcase weight was estimated to be a potential 3 per cent increase in equivalent live-weight without any change in stocking rate. Project 1.3.6 concerned the development of a meat science resource flock to provide the essential supply of slaughter lambs and yearling Merino mutton sheep of a required genotypic, nutritional history and age.

The outcomes of this sub-program were expected to deliver benefits to all sectors of the sheepmeats industry through the increased live-weight of culled animals and lambs and higher prices for mutton and lamb. The benefits were expected to result more from producers being able to capture premium prices for higher quality mutton and lamb than from significant increases in meat production. In on-farm meat production, quantifying the effect of 'all of life nutrition' on the expression of genetic potential for growth and muscle yield in prime lamb genotypes enable producers to better target market specifications. Meat processors should achieve efficiencies from the adoption of new generation electrical stimulation systems, while at the retail demand level, consumers will benefit from increased supplies of higher quality sheepmeats that better satisfy their quality requirements regarding meat tenderness, colour and odour.

Sub-Program 1.4: Parasite Management

Improved parasite control has made important contributions to productivity improvement in the Australian sheep industry since the 1940s following the development of effective chemical products. Significant advances in parasite control have been the recognition of the importance of the epidemiological relationship between environmental conditions and nematode abundance in pastures in the 1940s and 1950s, the development of strategic worm control programs based on worm ecology and epidemiology in the 1970s, the development of broad spectrum-based anthelmintics in the 1970s and 1980s, and the recognition of the importance and costs of chemical resistance in the 1980s and 1990s. The heavy reliance of past and current parasite control practices on chemicals has resulted in a level of resistance to anti-parasitic formulations that is now considered to be a major threat to sheep industry profitability. For internal parasites, a current research emphasis is to develop parasite management strategies based on reduced chemical use and includes the use of worm resistant sheep (Besier and Love 2003). Resistance by internal parasites to anthelmintic drenches is a serious threat to the sustainability of sheep production in many areas (RLPB 1998). Blowfly and lice control practices have also been affected by widespread resistance to insecticides, and moves to limit wool pesticide residues have highlighted the need for non-chemical control methods. Without new non-chemical methods of control, losses from parasites are likely to increase and there will be reduced opportunities for the sheep industry to enter the minimum-chemical and eco-label markets that reflect the increasing demand from consumers for chemical-free primary products.

Despite the long history of research into parasites, parasitic infections remain the most prevalent animal health problem in Australian sheep production (Besier and Love 2003). The costs of parasites to the sheep industries, mainly in the high rainfall and wheat-sheep zones, have been and still are substantial in terms of reduced production and control costs. Earlier economic studies in the 1960s and 1970s determined that parasites were a major source of sheep production losses despite the control efforts of sheep producers and the large volume of research that was directed at maintaining and improving parasite control. Twenty years ago it was estimated that the average annual costs of parasites to Australian sheep producers in terms of production losses and control costs were nearly $7,500 per farm (Beck *et al.* 1985).

Internal parasites accounted for two-thirds of that cost of which 83 per cent was due to wool production loss. The annual costs of preventing and treating blowfly strikes averaged $2,300 per sheep farm, while the costs of external parasites were relatively minor at $500 per farm. More recently, the annual losses to the sheep industry from blowflies, sheep lice and roundworms or nematodes were estimated to be $161 million, $169 million and $222 million, respectively (McLeod 1995). The cost of roundworm infestations is considered to be an underestimate since parasite resistance to chemical drenches was not considered in McLeod's (1995) estimate. Worm resistance has become a severe and widespread constraint on the effectiveness of worm control that has flow-on effects on the profitability of the sheep enterprises (Besier and Love 2003). It is considered that the cost of these parasites will be a conservative $700 million by 2010 as sheep numbers are reduced in response to increased worm resistance to drenches (Welsman 2001).

The emphasis of Sub-Program 1.4 was to develop new methods for sheep parasite control that utilise the objective assessment of treatment needs and non-chemical management strategies that will reduce costs, extend the life of current control methods and reduce the reliance on chemicals for control. A major objective for internal parasite control is to develop a range of accurate on-farm diagnostic tests that support the emphasis on cost-effective worm control and management decisions to counter anthelmintic resistance (Projects 1.4.1A-D). Specifically, these tests have enabled sheep worm burdens to be identified and quantified, improved worm egg detection and identification, and the identification of worm larvae on pastures to indicate the relative risk to grazing sheep. The emphasis on external parasite control has been to determine the potential for breeding and vaccination approaches to controlling blowflies by research into the genetic basis of flystrike susceptibility and immunological defence mechanisms (Projects 1.4.2A and B). Non-chemical control strategies that were investigated include the potential for nutritional supplementation to increase the immunity of sheep to worms (Project 1.4.3), and the use of electronic weighing equipment to identify individual sheep that are affected by worms and require treatment (Project 1.4.4). Producer access to current worm control information and local recommendations have been significantly enhanced through the development and successful implementation of the 'WormBoss' website (Project 1.4.5).

The expected economic benefits of improved parasite control in sheep production mainly relate to the opportunities to increase weaning percentages with lower mortality, to reduce animal health and labour costs, to minimise chemical use and to capture the benefits of individual animal management. Examples of the current costs of parasite control as a proportion of the total variable costs of sheep production (taken from New South Wales gross margin budgets) are 8.5 per cent for a Merino self-replacing flock and 11.2 per cent for Merino wethers (NSW Department of Primary Industries 2005). Reducing these costs would represent a significant saving. A preliminary external evaluation of the industry impact of the Sheep CRC calculated a benefit of $24 million annually from a 30 per cent reduction in the costs of parasites to the industry (Sheep CRC internal document 2002).

Sub-Program 1.5: Strategic Nutrition

Sheep producers face the challenge of having to respond to market demands for specialised wool and meat products that have to meet increasingly strict quality specifications. The objectives of Sub-program 1.5 were to assist sheep producers meet these specifications through the development of cost-effective nutritional strategies that could be adopted across Australia's different sheep producing environments. A focus was on determining profitable grain feeding systems for finishing prime lambs and cast-for-age ewes for mutton to assist producers respond to market specifications. It was expected that these strategies would enable producers to confidently use grain and other nutritional and management regimes to finish sheep in feedlots to better meet market requirements. Producers would also be able to segregate the highly productive portions of their ewe flocks for preferential nutrition to achieve target condition scores/weights so as to optimise reproductive efficiency and to produce lambs both for meat and for replacements in wool production systems. Improved nutrition was seen to be a major influence on sheep productivity through its static effects on body weight and condition and its dynamic effects through the rate of weight gain.

Project 1.5.1 concerned the development of intensive feeding strategies to better finish prime lambs according to market requirements. The use of improved feeding equipment systems to reduce feed wastage was also investigated. It was found for example, that the 7 per cent feed wastage from using bale feeders was substantially lower than the 45 per cent wastage from feeding bales on the ground. The intensive feeding of different types of grain to older sheep to increase body weight prior to sale was investigated under Project 1.5.2. It was found that there was considerable variation in the ability of older animals to readily adapt to grain feeding and that it was uneconomic to feed sheep with body weights that were initially too low to achieve the required growth rates. Carcase values were increased by up to $1 per kilogram for those animals that could be adapted to this type of feeding.

Project 1.5.3 examined the development of commercially viable nutritional strategies to maximise the reproductive performance of breeding ewes through the use of objective measurement and the individual animal management technologies that were developed in Program 2. This research established that a feeding system of targeted segregation and supplementation was more economic than either not feeding any ewes or feeding all ewes for the full period for which it was required, particularly when lamb marking percentages were low due to poor nutrition. Project 1.5.4 was a review of the sheep grain feeding for meat production literature, while Project 1.5.5 defined how selection for fleece characteristics or for growth rate interacted with the nutrient supply and affected the partitioning of nutrients between wool and meat production. The focus of the latter project, on the effect of promoting wool growth on meat production, was consistent with this issue having been identified as the main genetic problem in the Australian sheep flock. An important outcome was that the effect of fleece weight was found to depend on the nutritional environment, and hence the relationship between that variable with fatness was greater than its relationship with live weight.

The expected benefits from this program mainly result from improving the quality of lamb and mutton to capture the trend to higher lamb and mutton prices on the Australian domestic and export markets. Average saleyard lamb prices over the past two years have been two to three times what they were in 1999, while mutton prices have been more than threefold the average price over the 1990s. Export prices for sheepmeats have also risen substantially to the point where average lamb export prices since 2000 in the principal export markets in the United Arab Emirates and the United States have been 40 per cent and 60 per cent higher than the average prices over the 1990s. Similarly, the average price for Australian mutton in Japan over the same period has been double the boneless frozen beef price and 12 per cent higher than the price for chilled beef.

Program 2: Improving Profitability in the Sheep Industry

The development of precision production systems for individual sheep management has been a major emphasis of the Sheep CRC's research through Program 2. Because of the wide range of precision and management strategies available, sheep producers need to have access to objective information on the relative benefits and costs so that they can make adoption decisions that are consistent with individual constraints and circumstances.

The Sheep CRC has provided the opportunity to expedite the development and promotion of improved technologies (software and hardware interfaces) for individual animal management (IAM) throughout the wool and sheepmeat industries. As these technologies allow producers to adopt different approaches to managing their productions systems, it was considered that a detailed examination of the opportunities that are likely to yield improved economic returns to producers and all sectors of the sheep industry was most important. This practical area of research has highlighted knowledge gaps and the need for further investigations. It represented a major advance from the opportunities identified by theoretical modelling.

Precision sheep production for wool and meat based on IAM incorporated the genetics, nutrition and parasite management issues that comprised the sub programs of Program 1. Program 2 had the responsibility for developing effective technologies and management options to enable sheep producers to move from current flock management practices to systems that measure, manage and market animals or selected groups of animals according to individual merit. This IAM focus enables decisions to be made regarding selection on merit, management according to potential and selling based on market specifications. Such a large change in management emphasis has required a coordinated approach between producers, service providers and researchers. The program has identified the opportunities and benefits associated with different strategies for precision sheep management. It has delivered the integrated management systems that include computer hardware, software and support that have enabled these strategies to be applied and the benefits to be validated under commercial conditions. In this context, the role of the Sheep CRC was to facilitate and accelerate the development of integrated systems of electronic data capture and the effective use of that information in wool and meat production.

Research in Program 2 followed three linked areas of investigation. In broad terms, Project 2.1 concerned the identification of opportunities for IAM, Project 2.2 was concerned with enabling technologies, while Project 2.3 concerned the on-farm application of those technologies. The three component projects in Project 2.1 concerned the development, modelling and extension of on-farm wool fibre measurement (Project 2.1.1), the refinement of additional IAM strategies through the use of a bio-economic model of wool and sheepmeat production (Project 2.1.2), and the validation of these strategies under commercial conditions to determine those that were most likely to enhance productivity and profits (Project 2.1.3). The component projects under Project 2.2 concerned the evaluation and integration of electronic equipment and service providers for communication to the sheep industry (Project 2.2.1), accelerating the development of computer software and hardware that had links to the various decision support systems being used in the industry (Project 2.2.2), and the evaluation of a remote data storage system (Project 2.2.3). Under Project 2.3, two component projects examined the components of IAM that are related to the on-farm use of the technology such as electronic ear tags (Project 2.3.1), and the use of the IAM technology in the finishing of slaughter lambs via on-farm measurement and abattoir feedback (Project 2.3.2).

The expected production benefits from Program 2 are in terms of increased weaning percentages, reduced mortality rates and increased wool production with some reduction in micron. Because of their largely innovative nature, there have been few economic analyses of IAM technologies at the sheep industry level. Further application of weight and fat measures in lamb production, and use of on-farm measurement in breeding ewe management have been evaluated using the Sheep CRC’s internal methods. Under a very high discount rate of 15 per cent and limited adoption in the short term, a benefit-cost ratio of 4:1 was estimated. It was considered that in the longer term, these production systems needed to be a feature of the industry in order to achieve the substantial future benefits that were likely to result from precision parasite management, precision nutrition and automated monitoring and management processes. It was these developments that were the outputs from Program 1.

3. Economic Methods and Scenarios for Evaluations

There are three types of potential benefits from a new industry-wide research program, such as a Cooperative Research Centre (CRC) (Griffith *et al.* 2004). In relation to the Sheep CRC's programs, the first results from completely new research that has not been previously undertaken and would not have been undertaken without the Sheep CRC's investment, i.e. *new technologies* that would not have otherwise been generated. The second results from enhanced research outputs that have a greater impact on the industries than those that come from other research programs that may be undertaken by the same staff and agencies independently of the Sheep CRC, i.e. *better technologies* that come out of the Sheep CRC's research programs that improve on the outputs of other programs in similar areas. The third is the result of the extension to the industries of improved information that is legitimately attributable to the Sheep CRC's activities, i.e. the *faster and/or more widespread adoption* of new technologies.

The potential benefits from the Sheep CRC's research appear less likely to fall into the first category because there has been some research in most of the program areas given the long history of research in the Australian sheep industry. Hence, it is less likely that there will be future productivity improvements in sheep production that can be attributed to new technologies from the Sheep CRC's research. The benefits are more likely to fall into either the second or third categories or both, where the Sheep CRC's investment intensifies the level of research in the sheep industry by providing additional and more timely research funding.

In an evaluation of the CRC for Weed Management Systems, the CIE (2001a) described two possible approaches to evaluating the accountability of that CRC's achievements. The first was based on the evaluation of a set of projects that was randomly selected from the research portfolio, and the extrapolation of the benefit estimates to other research areas to determine the net overall benefit to the CRC. This method relied on a large sample size and its validity depended on how representative the selected projects were of the full research program. It was difficult to apply when only some projects were amenable to quantitative evaluation. Under the second method, a set of successful projects were selected and the extent to which their estimated returns covered the full research costs of the CRC was determined. This method was considered to be more tractable than the first but it was seen to generate less information. Elements of these two methods were used in these Sheep CRC evaluations. A modelling system was developed that indicated the nature of the economic benefits likely to emanate from the Sheep CRC's research, the anticipated impacts of the research on the sheep industry sectors, and their overall contribution to productivity growth in the sheep industry. An advantage of this system was that it allowed the programs and the component projects to be evaluated as being parts of an integrated research program, rather than as being standalone entities.

This modelling system and its information requirements are described in the following two sections. It has two main components. The first component contains the details of the economic procedures that were followed in evaluating the six research areas in Programs 1 and 2. This process utilised well-known economic methods that were applied in a 'top-down' context. The second component details the procedures that were adopted to evaluate a single project from each of the six research program areas. This evaluation method has a 'bottom-up' basis. The use of both these methods in evaluating major research programs has been described and recommended by the Allen Consulting Group (2003). Because the main emphasis of this analysis has been on evaluating the potential economic impacts of the programs, much of the following material relates to that purpose.

3.1 Evaluation scenarios

The Sheep CRC's research investment represents a continuation of a commitment to R&D in the Australian sheep industries and most of the program areas are supported by a strong information base. Hence, it can be expected that sheep research will continue without the Sheep CRC's programs, but at a lower level of funding, and there will be future productivity improvements in sheep production that can be attributed to the other research. The main effect of the Sheep CRC's research investment is to increase the breadth and intensity of the research effort and to expedite the delivery of the research outcomes to the sheep industry. This outcome is achieved by providing additional research funding and by reinforcing and expanding the strong collaboration that currently exists between researchers and the resources of the research institutions (Griffith *et al.* 2004). Further, the long-term nature of some of the technologies, such as genetic improvements over several generations, indicate that there will be some very long run impacts of the Sheep CRC's research on the sheep industries. These issues emphasise the importance of being able to define accurate evaluation scenarios that recognise that much of the research in the programs would have been undertaken at some point in time without the Sheep CRC.

The research evaluation task therefore was to measure the ***incremental*** benefits that could be ascribed to the Sheep CRC, ie., the benefits that were net of ongoing benefits from past research activities and net of any expected benefits from independent research programs. This required the definition of realistic *with* and *without*-Sheep CRC research scenarios for each research program to enable the incremental benefits to be properly and consistently estimated.

Defining relevant evaluation scenarios is recognised as being one of the most useful parts of the process of economically evaluating research but it is also often very difficult because most evaluations are usually concerned with on-going rather than new research. Alston *et al.* (1995) noted that the *with*-research scenario in this process often implies a baseline that presumes an indefinite continuation of the research program, whereas the *without*-research scenario often implies that none of the baseline research has been attempted. For that reason, the *without*-research scenario may appear to have little relevance in many instances since there has usually been some past research investment that establishes the baseline. For example, new crop varieties typically incorporate improvements from earlier crop breeding programs. Other evaluation scenarios embody different assumptions about the baseline. One possibility is that the *with*-Sheep CRC scenario involves a continuation of a research investment while the *without*-Sheep CRC scenario represents a funding reduction. Another is that the *with*-Sheep CRC scenario involves an expansion of a research investment while the *without*-Sheep CRC scenario represents a continuation of a research investment. This latter case is considered relevant to this Sheep CRC research evaluation.

These scenarios recognise that the Sheep CRC has not been fully responsible for the development of some of the technologies that have resulted from its research programs. Rather, the Sheep CRC has provided an important addition to the scale of Australian sheep research that has enabled the development and extension of new technology to be expedited and to produce research outputs that capitalise on the findings of past research.

3.2 Economic models

The objectives of agricultural research are considered to be mainly economic and concern the distribution of economic welfare (defined below) between social groups (Alston *et al.* 1995). Economic welfare is improved if technology adoption generates an increase in industry productivity. Where research has an industry focus, a productivity improvement can result either from an increase in production from a given resource level, or from maintaining a production level using fewer resources. The effect of a widely adopted productivity improvement is to shift the industry supply curve to the right. The extent of this shift is determined by the reduction in the unit costs of production following technology adoption. On this basis, the economic evaluations of the Sheep CRC research programs were done in an *ex ante* benefit-cost context in which the program costs were known and the benefits were estimates of the expected returns over a given period into the future. The following sections discuss the major issues that were addressed and the methods used in undertaking the evaluations.

Based on the evaluation scenarios outlined in Section 3.1, the potential benefits to the Sheep CRC's research programs were estimated as the differences in the impacts of the productivity improvements and research and adoption lags for the *with*- and *without*-Sheep CRC scenarios. To restate, it was considered that the main effect of the Sheep CRC's research programs was to generate shorter lags in delivering improved technologies to the sheep industry compared to the similar outcomes of research from other agencies. Another effect was to generate enhanced potential productivity improvements than would otherwise have been the case. The benefits to the Sheep CRC programs were the differences in the benefit levels that were generated by the research and adoption lag structures and by the productivity improvements that were given for the *with*- and *without*-Sheep CRC scenarios.

Economic surplus models. Benefits were estimated using the partial equilibrium measures of economic surplus or welfare changes that result from the adoption of a production-increasing technology in an industry. Economic surplus comprises two components: consumers' surplus, which is the difference between the benefits and costs of consumption; and producers' surplus, which is the difference between the returns and the costs of production. Three propositions in the theory of economic surplus as a welfare measure are that the demand price for a commodity represents its unit value to consumers, that the supply price represents its unit value to producers, and that welfare changes are additive across the economy irrespective of to whom they accrue (Harberger 1971). Accepting these propositions enables the welfare changes from technology adoption in an industry to be measured in terms of economic surplus changes. Alston *et al.* (1995) argue that this approach is the best available method to evaluate returns to research where differences in production costs from the adoption of a technology can be determined. Benefits include the potential welfare gains to producers from adopting the technology and the gains to consumers from reduced product prices where the industry-wide adoption of the technology leads to an increase in production.

To consider the Australian wool industry, Figure 3.1 illustrates those effects where the widespread adoption of a hypothetical wool production-increasing technology generates a parallel shift in the industry supply curve (S_0) on the assumption that the production cost reductions are uniform across the industry[1]. Q_0 represents the pre-adoption wool production and P_0 is the pre-adoption wool price. At point *a* the marginal wool producer is just making 'normal' profits, and the marginal consumer is just satisfying their preference for wool consumption. Between *a* and I_0, lower cost producers would continue to supply wool at lower prices to about point I_0, so they have an economic surplus gain from the higher price P_0 that they receive. This gain is represented by the area P_0aI_0. Wool consumers also have an economic surplus gain given by the area P_0aF because those with strong preferences for wool would be prepared to pay higher prices for wool up to *F* but they only have to pay P_0. The area of total economic surplus without the new technology is the area FaI_0.

Technology adoption shifts the wool supply curve to S_1 at the higher production level Q_1 which causes a fall in the wool price to P_1 since the aggregate demand for wool is downward sloping. Producers gain a larger economic surplus at the lower price given by the area P_1bI_1, while wool consumers' surplus is also larger (the area P_1bF) with an increased demand (Q_1 - Q_0) at the lower price of P_1. The increase in total economic surplus due to the shift in supply is given by the area I_0abI_1, or the difference between the areas FbI_1 and FaI_0.

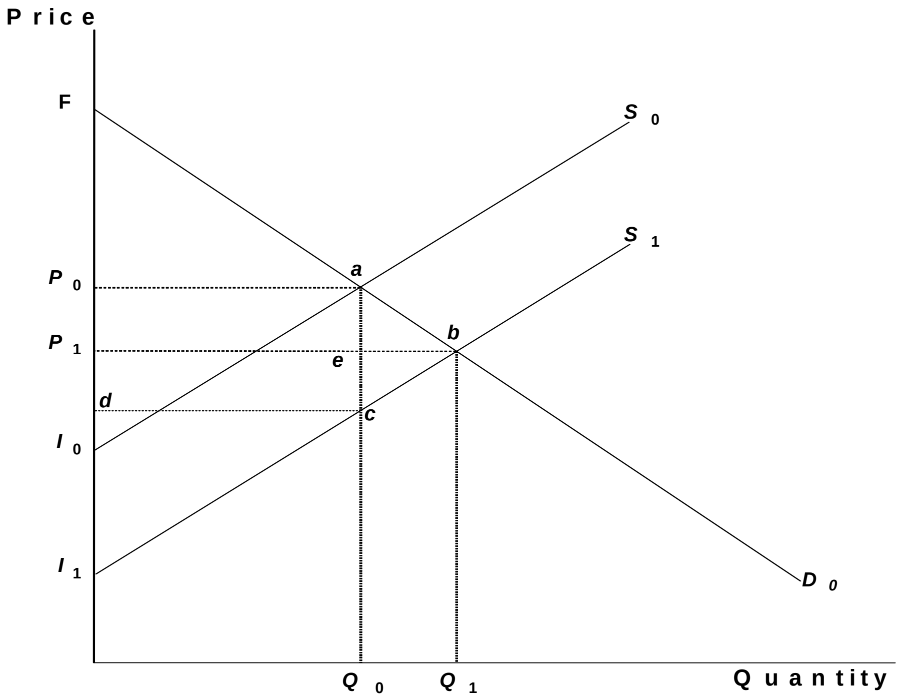

Figure 3.1. Economic surplus changes from the adoption of a production increasing technology

[1] This is the simplest type of economic surplus diagram that assumes a single homogeneous product, a single market level and a single closed economy or region with no trade in or out.

The area I_0abI_1 therefore represents the economic value to the wool industry from the adoption of the technology. After Alston *et al.* (1995), this area of economic surplus gain has two parts, (i) the cost saving on the original quantity that is given by the area (I_0acI_1) between the supply curves to the left of Q_0, and (ii), the increase in value at the new quantity equal to the increase in total consumption (the area Q_0abQ_1) less the increase in the total cost of the production (the area Q_0cbQ_1), given by the area *abc*.

Where the supply shift from wool technology adoption is parallel, the area I_0abI_1 is equal to the area P_0abcd. Also in this case, the distribution of benefits between producers and consumers is determined by the price elasticities of supply and demand. A price elasticity measures the response in a variable to a change in its own price, e.g. a measure of the change in the supply or demand for wool following a wool price change. An elastic response is one which is proportionally greater than the price change; the opposite holds for an inelastic response. The slope of the demand and supply curves broadly indicate the nature of the price elasticities and their relative slopes indicate the share of total benefits.

In this example, with the slopes of the demand and supply curves approximately equal, consumers and producers share the total benefits approximately equally (the top and bottom halves of P_0abcd are about the same). Consumers benefit from the increased wool supply that reduces the wool price. Even if the wool demand curve is perfectly elastic (horizontal) consumers are no worse off from the wool supply change, although there is no consumers' surplus since price does not change. Consumers gain most when supply is elastic and demand is inelastic. The net welfare effect on wool producers depends on whether the increased industry revenue at the higher production compensates for the price decrease. Producers can lose if demand is inelastic and only some producers adopt the technology (i.e. the supply shift is not parallel) and industry revenue falls as supply increases, but gain most under an inelastic supply and an elastic demand. The latter elasticity conditions relate to Australia's sheep and most of the other major livestock industries. Wool producers are therefore likely to derive the largest share of the benefits from new technology adoption in the Australian wool industry.

The economic surplus model illustrated in Figure 3.1 has limited applied relevance because of its restrictive assumption of a uniform price reduction across the industry that implies that the technology is adopted by all producers, and its closed economy-without trade context. On the first issue, Lindner and Jarrett (1978) considered that many agricultural technologies were location specific and that the best solution to the problems of applying the economic surplus model was to disaggregate the level of analysis. Undertaking a regionally disaggregated analysis recognises that differences in production environments between regions prevent technology adoption from being accurately modelled at an aggregate level. Australia's rural production systems have significant regional variations in resources and climates which means that the cost structures of producers and the effects of adopting a cost-reducing technology will also vary. The second issue that has to be accommodated in the evaluation process is the effects of new technology adoption on international markets. Where the industry is a significant contributor to international markets, as are Australia's sheep industries, the impacts of technology adoption on the foreign producers and consumers of sheep products are necessary considerations.

A disaggregated economic surplus model that incorporates the regional and international effects of new technology adoption is illustrated in Figure 3.2. This model has three production regions that vary sufficiently to have different cost structures (Davis 1994)[2]. Cost variations are indicated by the different intercepts and slopes of the supply curves that aggregate to form the industry supply curve. Price is the same in each region but the production levels vary; the latter are indicated by the different sloping segments of the global supply curve. Separate regional demands are not considered to be relevant in this example and the global demand determines the prices P_0 and P_1. In this model, technology adoption in region 3 increases production in that region but not in the other two regions.

The main effect of region 3's supply shift is to reduce price to P_1 in each region because all regions face the same national demand and the price differences P_1 - P_0 are the same in each region. Producers in regions 1 and 2 lose economic surplus as production falls in response to P_1, because they are unable to adopt the technology and the lower price forces a shift down the supply functions to quantities $QR1_1$ and $QR2_1$. This effect differs from region 3 where technology adoption lowers average costs and shifts production out to $QR3_1$. The global effect of the technology is the sum of the regional effects which in this instance, is to increase production to QN_1. The global increase in economic surplus is less than that in region 3 because of the losses to producers in the regions where the technology cannot be adopted.

The main points that Figure 3.2 shows are that the regions have supply curves with different slopes, that technology adoption in region 3 increases that region's production and reduces its price, that this price becomes the global price and that production in regions 1 and 2 decreases because of the price reduction. In the context of this model it is logical to consider that most new sheep technologies will be applicable regionally rather than industry-wide because of differences in production conditions. An advantage of using this disaggregated model is that by separating an industry into homogenous regions, a parallel supply shift will approximate the technology benefits to a region and enable the price spillover effects on other regions to be determined with less error (Davis 1994).

[2] These could be different regions within a country, or different trading countries in the world market.

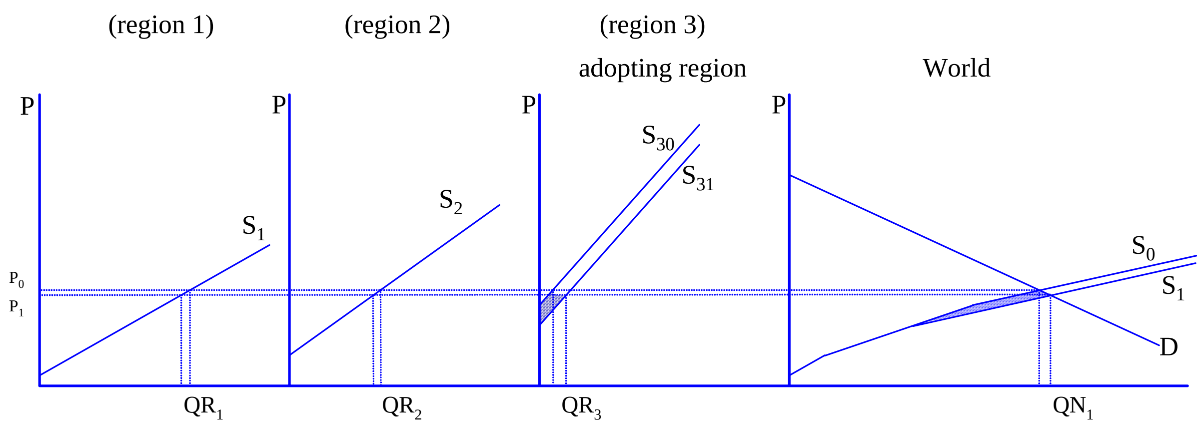

Figure 3.2. Regionally disaggregated economic surplus model (after Davis 1994)

The following formulae calculate the welfare changes for a three-region model in which a production technology that is adopted in region 3 results in equal price changes (to P_1) and price spillovers to regions 1 and 2.

Change in region 1 consumers' surplus:
(1) $\Delta CS_1 = P_0 Q_1 Z(1 + 0.5 Z \eta_1)$

Change in region 1 producers' surplus:
(2) $\Delta PS_1 = -P_0 Q_1 Z(1 + 0.5 Z \varepsilon_1)$

Change in region 2 consumers' surplus:
(3) $\Delta CS_2 = P_0 Q_2 Z(1 + 0.5 Z \eta_2)$

Change in region 2 producers' surplus:
(4) $\Delta PS_2 = -P_0 Q_2 Z(1 + 0.5 Z \varepsilon_2)$

Change in region 3 consumers' surplus:
(5) $\Delta CS_3 = P_0 Q_3 Z(1 + 0.5 Z \eta_3)$

Change in region 3 producers' surplus:
(6) $\Delta PS_3 = P_0 Q_3 (K - Z)(1 + 0.5 Z \varepsilon_3)$

The relative price change Z is defined as $-(P_1 - P_0)/P_0$, production and consumption are defined in Table 4.7, and ε and η are the price elasticities of supply and demand in each of the regions (Table 4.8). This model represents a price spillover between regions which benefits producers and consumers in the adopting region, and consumers in all regions, but producers in the non-adopting regions lose because they are unable to adopt the technology and so lower their production costs. It represents a realistic scenario for evaluating new technologies in Australian sheep production for the prior reasons, i.e. regionally specific technologies, export market strength and the likelihood of price spillovers.

Application of the disaggregated economic surplus model requires data on production, consumption and trade levels and estimates of the elasticities and the supply shift parameters. These data are usually derived from industry statistical records and previous industry studies which provide elasticity values. The data sources and procedures followed to determine the necessary parameter values are described in Section 4.

Structural model of the Australian sheep industry. While the simple industry structures shown in Figures 3.1 and 3.2 can be adequately represented by the equations outlined above, when industry structures become more complicated through more regions, more supply (and/or demand) shifts or more market levels, a more formal model of that structure is required to properly estimate changes in prices and quantities and subsequent changes in economic surplus areas.

There are several different types of structural models of an industry or market. One is the 'econometric' type of model. These are models whose key parameter values are estimated using statistical procedures from long series of historical data on the main influencing variables. Such a model does exist for the Australian sheep industry (Vere *et al.* 2000, Vere and Griffith 2004). This model was developed to represent the supply, demand and price formation processes of the wool, lamb and mutton sectors of the sheep industry. The use of this type of model is consistent with the economic surplus methods described above, under which it is necessary to capture the full price and quantity effects that are expected to result from the adoption of a new production-increasing technology in the sheep industries. The model is described in more detail in Appendix A.

An important feature of the econometric model is its ability to capture the high levels of seasonality that underlie the supply of and demand for Australian sheep products. Seasonality is evident in sheep production where pasture growth cycles strongly influence sheep breeding decisions. Also, there are biological constraints that result in time lags between breeding and product sales. These factors explain the price-inelastic nature of sheep production in the short to medium term. Seasonality is also found on the demand side of the Australian sheep industry in response to changes in consumer preferences through the year.

The problem with such models is that they are very data intensive, especially if specified on a quarterly basis, and it is a major task to keep updating the several hundred data series underlying the model. This is especially so when statistical agencies are continually cutting back on the data that they collect or report. Given these data issues, it was not considered worthwhile to undertake such a major update for this exercise.

Another type of structural model is the 'profit function' model. This is also econometrically based, but the focus is on estimating the determinants of the profits of representative wool producers instead of estimating the determinants of supply, demand and price linkage equations. Again, such a model does exist (Templeton *et al*. 2004) and it has been effectively used to evaluate some staple-strength technologies, but it requires further equations on the demand side of the market and it does not produce economic surplus measures in the form outlined above.

A third type of structural model is the ‘equilibrium displacement model’, or EDM. These models also fully represent the supply, demand and price formation processes of the industry of interest, and they are consistent with the economic surplus methods described above. EDMs are different from econometric models in that they are based on a snapshot of the industry in equilibrium at a point in time, and they estimate how the industry will respond to a displacement, such as a shift in a supply or demand curve, at some point in the future when a new equilibrium has been reached. They are usually based on price and quantity data for a typical or average year, and estimates of elasticities taken from published work or expert opinion.

There are EDMs available for many Australian agricultural industries (Zhao *et al*. 2000, Mounter *et al.* 2005, Hill *et al*. 2001). However those for the sheep industry are quite dated (Mullen *et al*. 1989, Mullen and Alston 1994) and a larger EDM of the sheep industry currently being developed under a Sheep CRC scholarship (Mounter *et al*. 2005) is not yet suitable for use in this exercise.

Fortunately, a structural model of the EDM form is embedded in the DREAM (Dynamic Research Evaluation for Management) benefit cost analysis software package. This software is based on the evaluation principles outlined by Alston *et al.* (1995), and it has been refined and promoted for use by the International Food Policy Research Institute (IFPRI 2001) and the Australian Centre for International Agricultural Research. DREAM has a rigorous theoretical base and requires well defined values for the main parameters that include the equilibrium prices and quantities, supply shifts, adoption rates and lags. One of the market specification options in DREAM, the horizontally disaggregated multi-region option (represented by Figure 3.2 and equations 1-6), was used to evaluate the Sheep CRC program benefits.

Benefit-cost analysis (BCA). The Sheep CRC’s research programs and the six individual projects were evaluated in an *ex ante* benefit-cost context in which the project costs were known and the benefits were projected estimates of the expected project returns in the future. Potential benefits were estimated in terms of the annual changes in economic surplus that resulted when the adoption of the program outcomes generated an outward shift in the supply functions for wool and sheepmeats. These estimates were made using the regionally disaggregated model detailed above. For both the program and project evaluations, benefits were assumed to commence after the time of the combined R&D and adoption lags (at the end of the Sheep CRC’s funding) and were projected over a 20-year period. All benefits were converted to the standard benefit-cost criteria, net present values (NPVs) and benefit-cost ratios (BCRs). A 5 per cent real rate of discount was used to reflect the social time preference rate, where that rate was defined as the long-term interest rate on government bonds less the current rate of inflation (see Rendell McGuckian 2001). Such relatively low real discount rates are most appropriate for government funding proposals. As indicated below, the benefit-cost analyses (BCAs) for the individual projects were simulated within the bounds of the probability distributions for the values of the major random variables given in Table 4.9.

The full list of projects that were included in the program evaluations is given in Table 2.1. Projects that were completed early in the Sheep CRC's term were included in the benefit estimates. Other projects that were cancelled during this term and were considered by management not to have delivered 'significant results' were treated as direct program costs, while several projects that had no direct production outcomes were treated as being underpinning science. Hence, all of the projects in the science programs were included in the 'top-down' evaluations. The costs of Programs 3, 4 and 5 were included as underlying costs of the Sheep CRC's research programs. It was taken as given that investment in education (the main thrust of these programs) was part of the public good component of the Sheep CRC's investment that should lead to reduced technology adoption lags and increased levels of technology adoption. The main outcomes of these programs, which included economic evaluations, industry training, post-graduate scholarships, industry seminars and other extension activities, were considered to be too diverse to be able to realistically apportion benefits. However, these programs were considered to be necessary for the full realisation of the Sheep CRC's potential benefits. All input data used in the BCAs are detailed in Section 4.

'Top-down' and 'bottom-up' research evaluation methods. In a major review of research funded by the Australian Research Council (ARC), the Allen Consulting Group (2003) distinguished between two general methods for quantifying research benefits. The first is a 'top-down' method that is designed to provide a benchmark or conservative estimate of the impact of research funding on productivity growth. Three parts of this 'top-down' process were identified in determining the impact of the ARC's research funding on productivity growth in the Australian economy. They were the extent to which all research in the economy (both public and private) contributes to productivity growth, the contribution to productivity growth made by publically-funded research in Australia, and the share of the impacts of that contribution that could be attributed to ARC-funded research. The purpose of using this method was to provide 'a plausible order of magnitude' of the impact of ARC research funding, rather than a precise estimate of the value of that impact.

The second is a 'bottom-up' method that involves a more complex examination of each of the areas of benefits resulting from ARC research activities. This method has a more specific focus on the individual research areas or the projects that make up the entire program and is considered to yield results that are as 'accurate an assessment of the returns on (ARC) research funding that can be obtained given available data'. In using a 'bottom-up' method, the expected outcomes from the individual program evaluations are aggregated to give a total program benefit. The main problem with this method in the context of a CRC is that the outcomes of some programs will be highly interrelated where they share resources or where the outputs of one program provides inputs into another. It can then be difficult to allocate costs across separate program areas and equally difficult to apportion the benefits. Such problems were encountered when the preliminary economic evaluations of many of the Sheep CRC's projects were undertaken in 2004.

For these reasons, the 'top-down' method was used to evaluate the main scientific research areas in Programs 1 and 2 (Figure 3.3). The use of this method for that purpose depends on being able to identify an underlying rate of productivity growth in an industry and to then assess the role of research-generated technological change in promoting that growth (Griffith *et al.* 2004). The main focus of the 'top-down' method in this application is to evaluate the Sheep CRC's research as an overall investment package since most of the production-based projects are grouped into program themes or clusters of projects and thus have similar objectives. This method was applied to the two scientific Programs 1 and 2. The 'bottom-up' method was also used to evaluate a project selected by the program leaders from each of the six Sheep CRC programs (Figure 3.4). This was done to provide a more detailed estimate of the potential benefits of these projects than could be obtained from the more aggregative 'top-down' method. The six projects selected were;

- Sub-program 1.1, Project 1.1.1: Genetic Analysis of Sheep Production Traits
- Sub-program 1.2, Project 1.2.6: Improved Sheep Meat and Wool Production Income
- Sub-program 1.3, Project 1.3.5: Hydration and Electrical Stimulation
- Sub-program 1.4, Project 1.4.5: On-line Sheep Worm Management
- Sub-program 1.5, Project 1.5.1: Grain Feeding Systems for Lamb Production
- Program 2, Project 2.3.1: On-farm Implementation Trials

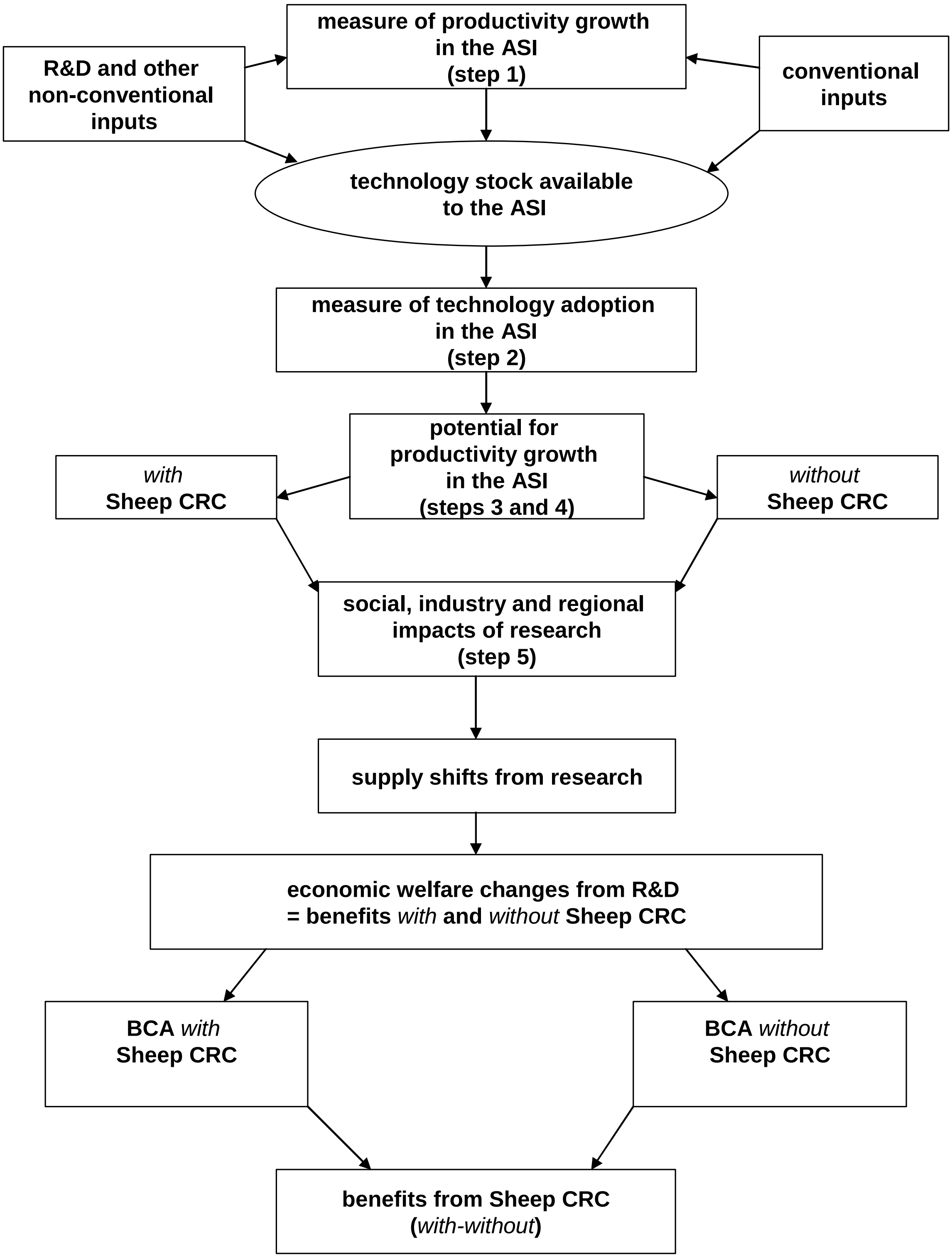

Figure 3.3. ‘Top-down’ process for evaluating the impact of the Sheep CRC’s research

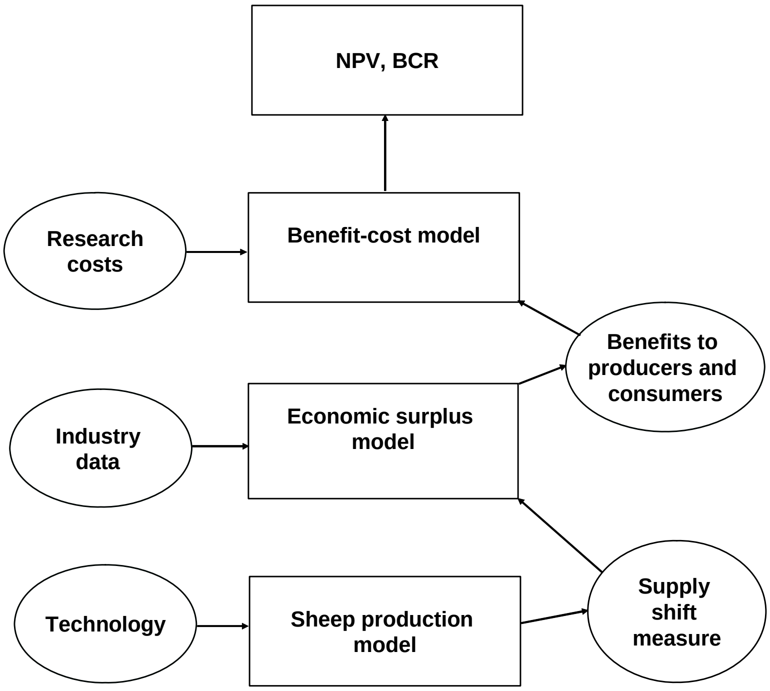

Figure 3.4. 'Bottom-up' method for Sheep CRC project evaluation

3.3 Summary of economic methods

The economic methods and applications described in this section are summarised below.

- The first part of this process was program based. Its purpose was to evaluate the economic benefits to the broadly-defined sheep industry that could result from the six research areas in Programs 1 and 2. A 'top-down' method was used, following procedures developed by the Allen Consulting Group (2003) to separately evaluate each research area in the two programs according to the defined *with*- and *without*-Sheep CRC scenarios. For each program, benefits were assessed in terms of the annual changes in economic surplus (or welfare) that could result from the industry-wide adoption of the programs' technologies. Program costs were derived from the Sheep CRC's financial records and included all direct grants and in-kind contributions, as well as the costs of Programs 3, 4 and 5 that were allocated proportionally to the six program areas. The benefit-cost calculations were made using the highly-respected DREAM model.

- The second part was project based and used a 'bottom-up' evaluation method. As for the program evaluations, these were evaluations of the potential industry benefits from a project selected from each of the six program areas by the program managers. Project benefits were similarly estimated in terms of annual economic surplus-welfare changes and matched against the project costs that were sourced from the Sheep CRC's accounts. Here, the benefit-cost calculations were made using stochastic models that enabled uncertainty about the values of the supply shifts and adoption variables to be directly simulated.

- There are two main differences between the program ‘top-down’ and project ‘bottom-up’ evaluations. The first is that the program industry-level supply shifts were estimated in terms of productivity growth contributions and allocated to the industry sectors according to the research impact proportions given in Table 4.4, whereas the project industry-level supply shifts were calculated from the production cost differences derived from the Rendell-McGuckian modelling. The second difference is that the benefit-cost calculations for the projects were stochastically simulated, whereas the corresponding calculations for the programs were not. These differences mean that the outcomes of the two levels of evaluation are not strictly comparable, although their purposes were the same and followed the same basic economic principles.

- Most of the input data regarding research impacts, research time lags, adoption ceilings and lags used in both the program (‘top-down’) and project (‘bottom-up’) evaluations were obtained from the program leaders and from the Rendell-McGuckian modelling that was independently undertaken by the Sheep CRC’s managers. Other input data such as elasticities, prices and quantities were derived from the literature.

4. Data and Other Information for Evaluations

An important issue in undertaking economic evaluations of major research programs is to obtain realistic information about the expected impacts of the research on the target industry. This requirement applies equally to the use of the 'top-down' method for evaluating research programs and the 'bottom-up' method for evaluating research projects.

There are six main requirements for implementing the 'top-down' method (Figure 3).
***(i) Derive estimates of underlying productivity growth in the Australian sheep industry*.**

This is a requirement to determine what the annual rate of productivity growth in the sheep industry has been over time so that it can be compared to the potential rate of growth that could result from the Sheep CRC's activities. Productivity growth is an important factor in offsetting the long-term decline in the sheep producers' terms of trade (i.e. the ratio of prices received to prices paid) that has been a feature of the Australian sheep industry since the mid-1970s (but less so over recent years). Apart from specialist lamb producers, productivity growth in the Australian sheep industry has been insufficient to offset this decline (ABARE 2004a). Future gains in sheep industry productivity are a major factor in determining the allocation of resources between wool and sheepmeat production, and are similarly important in maintaining and improving the sheep industry's international competitiveness (ABARE 2005). In national economic terms, productivity growth has accounted for two-thirds of the increase in Australian real incomes over the past 30 years (Industry Commission 1997). In this evaluation of potential research benefits, an estimate of the contribution of the Sheep CRC's research to productivity growth provides a link between that research and the long-term performance of the sheep industry and general economic growth (Allen Consulting Group 2003).

The economic concept of productivity concerns the relationship between the outputs and inputs of a production process. Productivity measurement indicates the relative rates of change in series of outputs and inputs over time. Productivity improvements in rural industries are typically either cost-saving or output-increasing (a supply shift), or quality-improving (a demand shift). Meaningful productivity measurement depends on being able to construct time-series of variables in either quantity or value terms in a manner that is consistent and economically relevant (Alston *et al.* 1995). Total factor productivity (TFP) is a commonly used measure of productivity change. TFP compares rates of growth in total output and total input use, and is defined as the change in the output quantity that is produced by a given quantity of inputs (Knopke *et al.* 1995). Productivity change can also be disaggregated into estimates of growth to the main inputs of labour, purchased inputs and land, to give measures of partial factor productivity (PFP). There has been a preference for TFP measurement because of practical difficulties in identifying the output contributions of separate PFP measures.

Growth in productivity occurs when the increase in output exceeds the increase in input use. The broad sources of output growth are in capital inputs, labour inputs and a 'residual' growth change that is not explained by conventional input use and is usually referred to as technical progress. There is no residual if the output growth is equal to input growth. The residual is the basic concept in the measurement and explanation of productivity growth (Antle and Capalbo 1988). Variables such as weather, education levels and expenditure on research and development have been used as explanations of changes in the TFP residual (Mullen and Cox 1995).

Mullen (2002) noted that one of the inputs that is typically not measured in (Australian) productivity growth studies is the flow of new technologies that results from investment in research by public and private institutions. It is the potential contribution of new technologies derived from publically-funded research to productivity growth in the Australian sheep industry that is the central issue in the economic evaluations reported here.

There is an extensive volume of literature on measures of productivity growth in Australian agriculture that has been derived using rigorous economic methods. Knopke *et al.* (1995) used index numbers to estimate that the annual rate of TFP growth in Australian broadacre agriculture averaged 2.7 per cent between the mid-1970s and the mid-1990s. There were large differences in productivity growth between the agricultural zones; 4.4 per cent for the pastoral zone, 3.3 per cent for the wheat-sheep zone and 1.3 per cent for the high rainfall zone. For the major industries, annual productivity growth was estimated to be 4.6 per cent for all crops, 3.2 per cent for mixed crops and livestock, 2.1 per cent for mixed sheep and beef, 1.6 per cent for beef specialists and 1 per cent for sheep specialists. Higher productivity growth in the cropping industries was attributed to large scale changes in cropping technology and production methods that included greater use of crop rotations, higher yielding varieties, nitrogenous fertilisers and the adoption of reduced tillage practices. The use of improved technology in the livestock industries had been less and these industries were more labour intensive than cropping. Mullen and Cox (1995) compared several index number and econometric cost function methods for measuring productivity growth and estimated that the rate of annual TFP growth in Australian broadacre agriculture estimated from these methods averaged 2.5 per cent over the period 1953 to 1994.

Lawrence and McKay (1980) estimated that TFP in the Australian sheep industry grew at annual rate of 2.9 per cent over the period 1952-53 to 1976-77. A similar sheep industry TFP growth estimate of 2.7 per cent per annum was made by Beck *et al.* (1985) from 1952-53 to 1982-83 with variations between years and climatic zones. Paul (1984) estimated a lower annual productivity growth rate for the sheep industry of 1.1 per cent over the period 1967-68 to 1981-82. These estimates were made using index number methods to aggregate series of outputs and inputs.

More recent TFP growth estimates for specialist sheep producers were 0.9 per cent per annum over the 25-year period 1977-2002. That estimate comprised annual growth rates of 0.6 per cent between 1977 and 1990, and 1.2 per cent between 1989 and 2002 (ABARE 2004b). The growth in TFP for specialist lamb producers was much larger at 1.6 per cent over the 25-year period. For all specialist sheep producers, the PFP estimates were 1.5 per cent for labour, 3.4 per cent for capital, 0.9 per cent for purchased inputs and -1.1 per cent for land. The corresponding PFP estimates for specialist lamb producers were 3.3 per cent, 3.5 per cent, 0.2 per cent and -0.6 per cent, respectively.

These data suggest that there was a substantial lift in productivity in the sheep industry during the 1950s and 1960s, and then a marked fall off in growth in productivity from the 1970s. It is also well recognised that productivity growth in the sheep industry has lagged behind growth in competing land use industries. Cropping, beef, dairy and forestry industries have all achieved higher productivity gains than sheep over the past decade, with the result that capital investment has been attracted away from the sheep industry (Sheep CRC Strategic

Plan 2003-08). Based on the historical growth estimates given in Table 4.1, the underlying rate of productivity growth in the Australian sheep industry was assumed to have averaged 1 per cent per annum in the recent past.

Table 4.1. Estimates of long-term productivity growth in the Australian sheep industry

Period	Industry sector	TFP growth (% pa)	Source
1952-73 to 1976-77	all sheep producers	2.9	Lawrence and McKay (1980)
1952-73 to 1982-83	all sheep producers	2.7	Beck *et al.* (1985)
1967-68 to 1981-82	all sheep producers	1.1	Paul (1984)
1975-1995	all sheep producers	1.0	Knopke *et al.* (1995)
1977-1990	specialist sheep producers	0.6	ABARE (2004b)
1989-2002	specialist sheep producers	1.2	ABARE (2004b)
1977-2002	specialist sheep producers	0.9	ABARE (2004b)
1977-2002	specialist lamb producers	1.6	ABARE (2004b)

(ii) Derive estimates of technology adoption in the Australian sheep industry. The second requirement is to estimate what the general rate of technology adoption has been in the sheep industry. It is generally accepted that the rate of uptake of improved production technologies in the Australian sheep industry has been low relative to other rural industries, and this has placed an effective constraint on the achievement of productivity gains by the industry (Sheep CRC Strategic Plan 2003-08). In the wool industry, technology adoption has usually been measured in terms of rates of producer participation in industry-promoted programs. Butler *et al.* (1995) found that the adoption of objective measurement and other breeding developments in wool production was low despite the extensive promotion of the potential for increased genetic gains. Reasons for low adoption included a reluctance to alter traditional selection practices, the costs of fleece testing and a perceived limited potential for genetic improvements.

Low adoption is also evident across different types of sheep production technologies in regional areas. Robertson and Wimalasuriya (2004) used a whole-farm linear programming model of sheep production in north-western Victoria to estimate the productivity changes likely to result from the adoption of improved technologies in animal health, reproduction, nutrition, genetics, pasture improvement and the direct marketing of lambs. They compared actual rates of adoption measured from producer knowledge of these technologies with a general rate of adoption of 25 per cent for new technology that was assumed to result from wider extension. The finding of a low average actual adoption rate of 14 per cent (across ten technologies) ranged between 65 per cent for reducing flock ram percentages to less than 5 per cent for vaccination, early weaning of lambs, grain feeding lambs and reducing wool fibre diameter. This finding was noted as being consistent with various other studies that have indicated a low rate of adoption of technologies that were proven to increase sheep productivity. Examples of wool industry-sponsored programs that have had a low measured adoption rate include a 15 per cent participation rate by Victorian wool producers in the Bestwool 2010 program (AWI 2003), 7 per cent of Merino breeders and 20 per cent of all sheep breeders using quantitative genetic services developed by the industry (Welsman 2000), and only 8 per cent of mainland wool producers using on farm fibre measurement technologies (AWI internal document 2005). These low rates of adoption contrast markedly with recent *ex ante* projections of profitable returns to the wool industry's investments in research and development (AWI 2003, Welsman 2001).

There have been no estimates of what the overall rate of technology adoption might have been in the sheep industry over time. Griffith *et al.* (2004) assumed a 25 per cent rate of adoption of new technologies in the Australian beef industry on the basis of anecdotal evidence and scientific opinion that suggested that the uptake of new technology by beef producers was relatively low. The evidence suggests that a comparative adoption rate for the sheep industry could be even lower, and this contention appears to be supported by the studies indicated in the previous section and by the Robertson and Wimalasuriya (2004) estimate of 25 per cent adoption for enhanced extension strategies. On that basis, a 20 per cent rate of new technology adoption has been assumed for these sheep evaluations. This assumption is reasonable as the rate of annual productivity growth in the beef industry of between 1-1.5 per cent is relatively similar to 1 per cent that has been assumed for the sheep industry. When combined with the estimate of measured productivity growth, the assumed level of new technology adoption enables a potential rate of productivity growth that could be realised by the sheep industry to be determined. The assumed 20 per cent rate of technology adoption for the sheep industry implies that there is a potential for full productivity growth of about 5 per cent, or an additional 4 per cent on top of the actual rate of growth that is not currently being realised. The presumption is that the Sheep CRC could help to move closer to that potential by expediting the release of new technology and promoting its adoption.

(iii) Determine the potential contribution of the Sheep CRC to productivity growth in the Australian sheep industry. This requirement estimates the increase in annual productivity growth that is expected to result from the Sheep CRC's research. The potential impacts of a given CRC's research on an industry's productivity growth are illustrated in Figure 4.1 for three possible situations. Each situation compares the potential for productivity growth with the actual rate of growth that is being achieved within the industry. As described above, the actual growth rate (AG_1) is derived from published estimates such as those given in Table 4.1, while the potential rate of productivity growth (PG_1) is determined from AG_1 and the assumed level of technology adoption in the industry. The vertical line (*ab*) represents the completion of the CRC's full term of funding when the benefits are assumed to commence.

Panels (*a*) and (*b*) represent two converse situations. In the first, the CRC does not add to the technology stock but invests in achieving a greater level of adoption of the existing technologies. This investment generates industry benefits by increasing the technology adoption ceiling and by reducing the adoption lag or the time required to attain that ceiling. Increased benefits result from the larger part of the industry adopting the existing technology and the reduced effects of discounting when the values of the benefits are estimated over the shorter adoption lag. While the potential growth rate remains unchanged at $PG_{1,}$ the Sheep CRC's investment increases the actual rate of productivity growth to AG_2. The focus of the (completed) CRC for Weed Management Systems is represented by this situation, where that CRC invested in improving the adoption of existing technologies that included the control of annual grasses in temperate pastures (Vere *et al.* 2003).

The second situation in panel (*b*) represents the opposite effect where a CRC adds new technologies to the existing stock but does not invest in increasing the level of technology adoption in the industry, and so there is no change in the adoption ceiling. Here, the CRC's research provides new opportunities for cost savings over those that are currently being achieved by the established group of adopters that comprise the adoption ceiling, such as the assumed 20 per cent in the sheep industry. The potential growth rate increases to PG_2 and the actual productivity growth is dragged along to AG_2 because the same *proportion* of producers is adopting the more effective technologies. However a potential remains for larger industry benefits that cannot be realised without also improving the adoption profiles.

Panel (*c*) is a combination of the first two situations and essentially represents the investment focus of the Sheep CRC in the development of new technologies and in improving technology adoption in the sheep industry. Here, the investment in new technology development is smaller than in the situation depicted in panel (*b*), so the potential rate of productivity growth is reduced from PG_2 to PG_3, but AG_3 is higher than AG_2 because of the concurrent investment in adoption.

The main points that are illustrated in Figure 4.1 are (i), there is a large difference between the potential and actual rates of productivity growth, as is the case with the Australian sheep industry; (ii), the research activities of a CRC provide new opportunities for cost savings in addition to those that are being realised by the industry's adopter group, as under the *without*-CRC scenario; (iii), if there is no investment in developing new technologies, there is no change in the underlying potential for productivity growth and the actual rate of growth can only be increased through higher adoption, and (iv), increasing both the technology stock and its level of adoption has the potential to generate substantial industry benefits. The advent of the Sheep CRC has provided the opportunity to increase the use of existing technologies, to add new technologies to the current stock and to improve the level of adoption of the technology stock. Economic evaluations in other Australian CRC's relating to weeds and the beef industry have demonstrated that new investment in technology generation and in enhancing its adoption has a significant economic value (see for example, Griffith and Vere 2005).

(iv) Determine the share of the assumed potential productivity growth contributed by the various outcome areas. As there has been no previous analysis of this issue, these estimates were obtained as opinions from program leaders and industry experts. Program leaders were asked to estimate the share of any expected increase in productivity growth that they expected to result from their respective programs. The estimates were circulated for second-round opinions and agreement was reached as to what the growth shares were expected to be across all programs. Members of the Sheep CRC's Industry Advisory Committee were then asked to validate the program leaders' estimates.

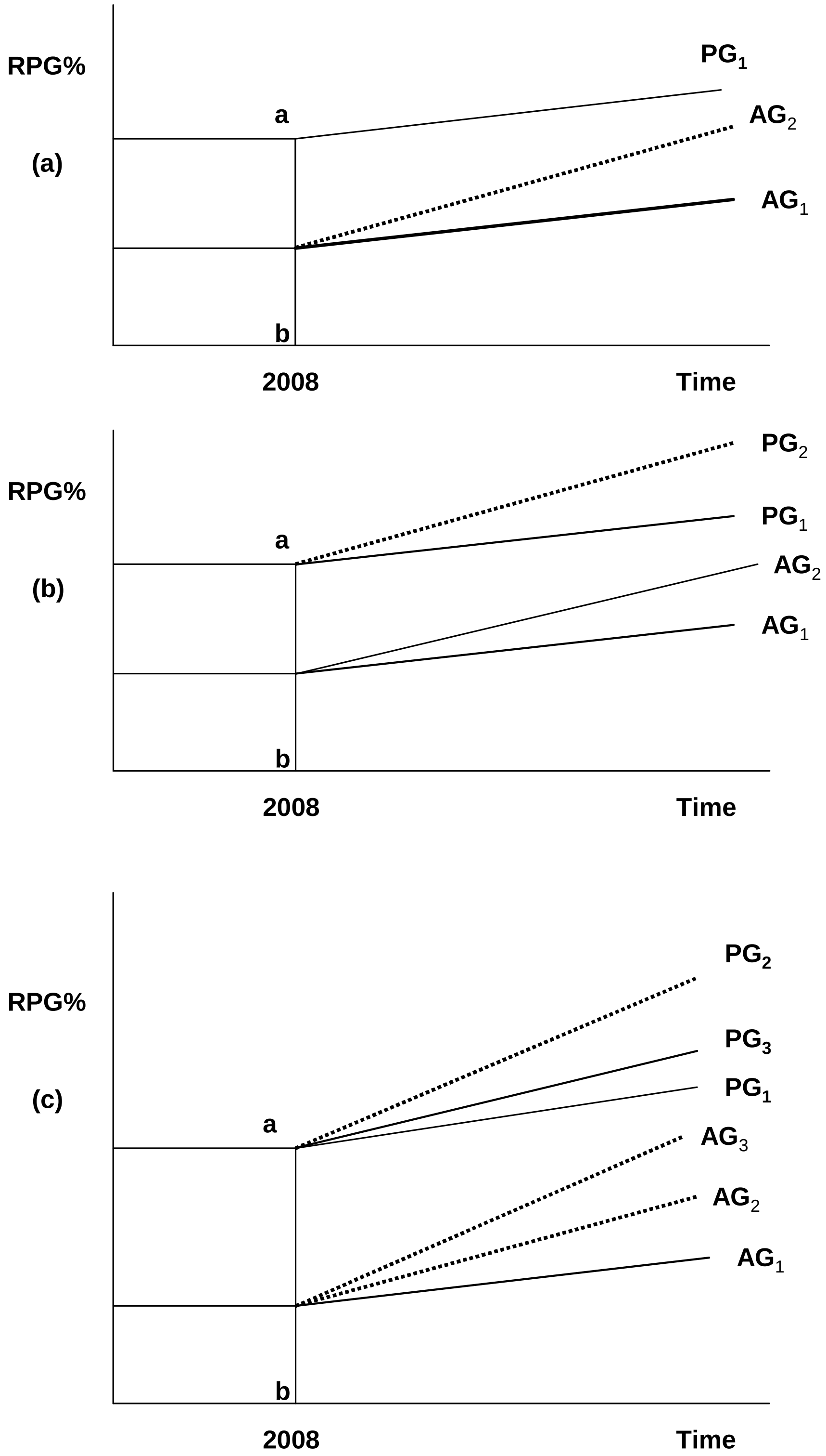

Figure 4.1. Possible contributions of a CRC to the rate of productivity growth (RPG) in an industry

Table 4.2 indicates the expectations of the program leaders and industry representatives as to how the components of the future productivity growth rate might be allocated between the types of impacts that could result from the Sheep CRC's research programs. Taking the mean values of both sets of estimates, the last column of Table 4.2 shows the expected percentage contributions of the programs to productivity growth. Thus, 21.3 per cent of the total growth is expected to come from the Meat Science program, 19 per cent from the Parasite Management program, 17.5 per cent from Genetics research, and so on. These values were taken to hold for the whole Australian sheep industry, and were the starting values used in the 'top-down' evaluations.

(v) Determine the industry, sectoral and regional impacts of Sheep CRC research. The fifth requirement of the process is to categorise where the research programs are expected to mainly impact in terms of (i) which part of the sheep industry – wool, sheepmeat or both; (ii), which side of the industry (supply or demand) and (iii), whether the technology is yield increasing, cost saving or demand enhancing. These estimates were obtained from the project leaders.

Table 4.2. Sheep CRC research program contributions to productivity growth

Program	**Relative program contributions to the annual rate of productivity growth** [a]						**Mean**	**Adjusted mean** [b]	**Mean estimate**
	Sheep CRC program								
	1.1	**1.2**	**1.3**	**1.4**	**1.5**	**2**			
Genetics	0.25	0.15	0.15	0.20	0.15	0.10	0.175	0.176	0.175
Wool science	0.10	0.20	0.05	0.10	0.20	0.05	0.125	0.106	0.115
Meat science	0.15	0.15	0.35	0.20	0.20	0.20	0.200	0.226	0.213
Parasites	0.10	0.20	0.20	0.20	0.15	0.25	0.183	0.198	0.190
Nutrition	0.20	0.15	0.10	0.15	0.15	0.10	0.142	0.102	0.122
IAM	0.20	0.15	0.15	0.15	0.15	0.30	0.175	0.193	0.185
Total (%)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[a] estimates of program leaders; [b] adjustments to program leaders, estimates by the Sheep CRC's Industry Advisory Committee.

(vi) Determine the potential for productivity growth in the Australian sheep industry, with and without the Sheep CRC. This requirement compares the potential rate of productivity growth in the sheep industry under the *with*-Sheep CRC scenario to that which is likely to occur under the *without*-Sheep CRC scenario, as defined in Section 3.1. As previously indicated, this step recognises that there would be a level of research in most of the program areas without the Sheep CRC, and so it is necessary to separate the benefits from this past research from the expected benefits from the Sheep CRC's research.

In determining the potential for productivity growth attributable to the proposed CRC for Beef Genetic Technologies, Griffith *et al.* (2004) drew on a number of past studies of productivity growth in the Australian beef industry and estimates of adoption levels to decide that the underlying potential rate of productivity growth that was available to this industry was about 5 per cent per annum. Based on recent economic estimates of the benefits of specific technologies and the CRC scientists' expectations that future successes would be duplicated through the CRC funding, it was further estimated that the aggregate impact of the proposed CRC on the potential rate of growth was an additional 4 per cent, following maximum adoption of that CRC's research outcomes. This was particularly the expectation in northern Australia where very large benefits were anticipated to be realised from the adoption of new beef breeding technologies and high additional rates of productivity growth of between 5 and 8 per cent were implied. The additional 4 per cent productivity growth that was held to be attributable to the proposed CRC took account of the possible over-optimism of the scientists and the real risks involved in achieving such high levels of benefits.

There were few similar published estimates of the economic benefits of new sheep technologies available to base an estimate of the potential contribution of the Sheep CRC to industry productivity growth. Given the degree of similarity in the mainstream research areas in the sheep and beef industries (e.g. genetic improvement, parasite management and nutrition), and the past history of productivity growth in both industries, the potential Sheep CRC contribution to annual productivity growth in the Australian sheep industry was held to be an additional 2.5 per cent, or a little over 60 per cent of the corresponding growth estimate for the beef industry.

Table 4.3 shows how these distinctions were made for the Sheep CRC evaluations. The underlying potential rate of productivity improvement available to the Australian sheep industry was estimated to be 5 per cent annually. This was derived from the measured rate of productivity improvement of about 1 per cent per annum and the observed low rates of adoption of new technologies in the sheep industry of about 20 per cent. The current rate of 5 per cent potential growth was assumed to be able to be maintained into the future if the Sheep CRC was not funded, given the researchers and agencies involved. Therefore, the maximum potential rate of productivity growth that could be achieved by the industry with Sheep CRC funding was taken to be 7.5 per cent, where it was assumed that the Sheep CRC could improve the underlying rate by 50 per cent.

These assumptions are summarised in Table 4.3 and explained in the box insertion. The growth proportions for each of the research program areas were then calculated as the product of the growth rate potentials and the estimated research program area contributions to that growth from Table 4.2. This gave the proportions of the growth potentials for the two scenarios that could be attributed to the research areas. Here, it was assumed that the expected contributions to productivity growth from the program areas were the same for both the *with*- and *without*-Sheep CRC scenarios as there was no basis for presuming that the Sheep CRC's contributions would be greater.

Table 4.3. Sheep CRC impacts: contributions to productivity growth in the Australian sheep industry by program areas

	***With*-Sheep CRC (7.5% growth potential)**		***Without*-Sheep CRC (5% growth potential)**	
Program area	**Research contribution (%)**	**Growth proportion (%)[a]**	**Research contribution (%)**	**Growth proportion (%)[a]**
Genetics	0.175	1.312	0.175	0.875
Wool science	0.115	0.863	0.115	0.575
Meat science	0.213	1.597	0.213	1.065
Parasites	0.190	1.425	0.190	0.950
Nutrition	0.122	0.915	0.122	0.610
IAM	0.185	1.388	0.185	0.925
Total (%)		7.5		5.0

[a] proportion of productivity growth potential

The productivity growth proportions were then disaggregated according to the sector of the sheep industry in which the programs were expected to have their main impacts. This was done by requesting the program leaders to rank the individual projects within their programs in terms of the expected percentage impacts on either the supply or demand sides of the wool and meat industries (Table 4.4).

Table 4.4. Sheep CRC impacts: proportional impacts of programs in industry sectors [a]

Program area	**Wool supply (%)**	**Wool demand (%)**	**Meat supply (%)**	**Meat demand (%)**	**Total program impact (%)**
Genetics	70		30		100
Wool science	50	33	17		100
Meat science			50	50	100
Parasites	58	3	39		100
Nutrition	20		80		100
IAM	49		51		100

[a] estimates of program leaders

The project rankings for each program were then totalled to give the proportional sector impacts of each program (Table 4.5). As examples, the 1.312 per cent growth proportion for the genetics Sub-program 1.1 under the *with*-Sheep CRC scenario was split 0.919:0.394 between wool supply and meat supply, while the 1.065 growth contribution of meat science research under the *without*-Sheep CRC scenario was evenly split between meat supply and meat demand.

Table 4.5. Sheep CRC impacts: allocations of growth proportions by industry sector

***With*-Sheep CRC**					***Without*-Sheep CRC**			
Wool supply (%)	**Wool demand (%)**	**Meat supply (%)**	**Meat demand (%)**	**Program area**	**Wool supply (%)**	**Wool demand (%)**	**Meat supply (%)**	**Meat demand (%)**
0.919	-	0.394	-	Genetics	0.613	-	0.263	-
0.431	0.285	0.147	-	Wool science	0.288	0.190	0.098	-
-	-	0.799	0.799	Meat science	-	-	0.533	0.533
0.827	0.043	0.556	-	Parasites	0.551	0.029	0.371	-
0.183	-	0.732	-	Nutrition	0.122	-	0.488	-
0.678	-	0.709	-	IAM	0.452	-	0.473	-
3.038	0.328	3.337	0.799	Totals (%)	2.026	0.219	2.226	0.533

The expected contribution of the Sheep CRC's research programs to productivity growth in the Australian sheep industry

Griffith *et al.* (2004) derived three essential sets of data as a starting point to their 'top-down' economic analysis of the proposed **CRC for Beef Genetic Technologies** (Beef CRC). In recognition that new technology adoption is a fundamental source of productivity growth in an industry, these data were the;

- actual rate of productivity growth in the Australian beef industry,
- rate of productivity growth that the beef industry could potentially achieve and,
- expected contribution to productivity growth by the proposed Beef CRC.

Formalising these data enabled the proposed Beef CRC to be evaluated in terms of the expected economic impacts of its research programs on beef industry productivity growth.

A review of previous economic studies of productivity growth in the Australian livestock industries provided the first set of data. That literature suggested that the annual rate of beef industry productivity growth averaged 1.25 per cent over time. This growth rate was matched against the available evidence of technology adoption in the beef industry. Since there was no quantitative literature on beef technology adoption, anecdotal evidence and expert opinion suggested that the level of new technology uptake by beef producers and processors was around 25 per cent. Both these estimates enabled the second set of data to be determined. Here, the potential rate of productivity growth available to the beef industry was calculated to be 5 per cent per annum (1.25 * 4), compared to the 1.25 per cent per annum currently being achieved. The current potential rate of growth and the current adoption pattern were assumed to continue into the future if the proposed Beef CRC was not to be funded.

The third data set was derived from beef industry expert opinion and estimates of the economic benefits of recently completed major beef genetics research programs. The authors estimated that the total industry impact of the proposed Beef CRC would be to add 4 per cent to the 5 per cent potential, giving a total potential growth rate of 9 per cent annually. This growth would be achieved after full adoption of the proposed Beef CRC's research outcomes. It reflected recent estimates of potentially large benefits to specific beef genetic technologies (the main focus of the proposed Beef CRC), and the expectation of the scientists that Beef CRC funding would provide the resources necessary to reproduce such successes in the future. The 4 per cent addition to annual productivity growth was considered to be conservative when the likely risks involved in duplicating such high payoffs were taken into account. The proposed Beef CRC had a strong focus on accelerated adoption and commercialisation, so it was also expected that the adoption ceiling would be raised and the adoption profile shortened. This resulted in an expected actual rate of productivity growth with the Beef CRC of a little over 3 per cent per annum.

The main use of these data was to determine the expected contributions of the various outcome areas of the proposed Beef CRC's to the 9 per cent potential growth rate. These contributions were based on the consensus values of the scientists after extensive consultations during the Beef CRC renewal process. The estimated contributions of the outcome areas to a 1 per cent growth in beef industry productivity were:

- increased beef quality (0.2)
- reduced feed costs (0.1)
- reduced input costs (0.1)
- increased market access (0.1)
- increased yield (0.1)
- increased reproduction (0.3)
- miscellaneous enhanced management (0.1)

These estimates indicate, for example, that 20 per cent of the total impact of the proposed Beef CRC research was expected to come from beef quality improvement and 10 per cent was expected to come from reducing feed costs. The growth contributions were further disaggregated to capture the impacts of the technologies on the northern and southern parts of the industry, whether the technologies impacted on the supply or demand side of the industry, and whether the technologies were cost saving or yield increasing. These disaggregated values were then used in the economic models to determine the potential economic benefit to the proposed Beef CRC. This incremental or marginal benefit was the difference in the estimated benefit from the proposed Beef CRC and the benefit that the beef industry would gain from the normal research flow if the proposal was not funded.

This evaluation of the **Sheep CRC's** research programs followed the 'top-down' methods developed for the proposed Beef CRC that had previously been described by the Allen Consulting Group (2003). For the first data set, the economic literature on sheep industry productivity growth was examined to determine an actual annual growth rate of 1 per cent (compared to the beef industry's 1.25 per cent). For the second data set, a 20 per cent level of technology uptake was assumed (compared to 25 per cent for the beef industry) on the basis of studies that indicated low adoption of new technologies by Australian sheep producers. The underlying potential rate of productivity growth available to the sheep industry was then estimated to be 5 per cent annually. This rate is the same as for the beef industry but it is based on a lower actual growth rate and a lower adoption level; the calculations are 1.25 * 4 (or 25 per cent) = 5 for beef, and 1 * 5 (or 20 per cent) = 5 for sheep.

In the beef industry example, the proposed Beef CRC was expected by the scientists to add an extra 4 per cent to the underlying 5 per cent potential productivity growth (or an 80 per cent improvement). The corresponding sheep industry estimate was scaled down to a 50 per cent increase in the potential growth rate to give a 7.5 per cent potential rate of growth with the Sheep CRC. The down-scaling from the beef industry estimates reflected the consistently lower measured rates of productivity growth and rates of adoption of new technologies in the sheep industry.

As for the Beef CRC evaluation, these data sets were then used to determine the expected contributions of the Sheep CRC's scientific programs to the 7.5 per cent productivity growth rate. These contributions were similarly based on the consensus values of the programs' scientists which were validated by the Sheep CRC's Industry Advisory Committee. The program contribution estimates to a 1 per cent growth in sheep industry productivity were:

- genetics (0.175)
- wool science (0.115)
- meat science (0.213)
- parasite management (0.190)
- nutrition (0.122)
- IAM (0.185)

Examples of these sheep estimates are that 21 per cent of the research impact was expected to come from the meat science program and 18.5 per cent from individual animal management. These impacts estimates were also disaggregated to the supply or demand side of the wool and sheepmeats industries, and were categorised as being either cost saving or yield increasing. All these values were used in the economic models to evaluate the potential economic benefits to Sheep CRC Programs 1 and 2. Again, this was an incremental benefit that was the difference in the benefit levels between the *with*- and *without*-Sheep CRC scenarios.

Evaluation procedures

The Sheep CRC evaluations were undertaken in two stages. In the first, Programs 1 and 2 were evaluated using a 'top-down' method that incorporated measures of industry productivity growth and the expected contributions to that growth from the programs, as detailed above, to calculate the product supply shifts that could result from the adoption of the programs' technologies in the Australian sheep industry. The benefits were calculated in terms of the changes in economic surplus that include the gains to sheep producers and to wool and sheepmeat consumers from widespread technology adoption. These changes were calculated using the DREAM model, as described above.

The horizontally disaggregated multi-region option enabled the potential economic impacts of the programs to be evaluated across the domestic and export markets that define the Australian and world sheep industries. However, the use of this option in focussing on the multi-regional and traded status of the sheep industry precluded the evaluation of the potential impacts of the programs on the vertical market segments of the industry, such as on processors and retailers.

The impacts that were evaluated therefore related to the farm-level as the point of exchange and the price, quantity and elasticity values chosen reflected this part of the sheep industry. Two further constraints with the use of the DREAM model were that it is only possible to analyse one product market at a time, so joint impacts on the wool and sheepmeats markets could not be evaluated[3]. Also, only a supply shift or a demand shift could be analysed, but not both in the one simulation of the model.

In applying the DREAM model in these Sheep CRC evaluations, the separate regions were defined as Australia, China, the European Union, New Zealand and the rest of the world (ROW). Because the DREAM model operates in an equilibrium displacement context, it uses equilibrium values for the input prices and quantities that define the size and structure of the market in each region. It also uses elasticities of supply and demand to predict how producers and consumers in each region will react to new prices generated by the simulated shocks to the market from the impact of the programs, and estimates of how the programs' technologies would change producers' cost structures or consumers' willingness to pay for different quality products in the region where the technology will be adopted (i.e. the *K* shift that is described below). All general input data used in these calculations are given in Table 4.6, equilibrium prices and quantities for each region are given in Table 4.7, while the estimates of the supply and demand elasticities are given in Table 4.8. Because the domestic sheepmeat demand elasticities derived from the literature related to the retail level, their values were reduced to be consistent with the production level context in which this evaluation was undertaken (Griffith *et al.* 2001). This scaling was based on the ratio of the weighted average production-level and retail lamb and mutton prices used in the modelling ($3.30 and $7.25 per kilogram, respectively).

The second stage was to evaluate a selected project from each of the five sub-programs in Program 1 and one project from Program 2, using a 'bottom-up' method. Following the approach of the Allen Consulting Group (2003), this was done to provide more specific estimates of the potential returns to some of the individual project areas. It was also done to explicitly incorporate the effects of the uncertainty that was more likely to surround the values of the critical supply shift and adoption profile parameters for an individual research project than for a broader research program. The reasoning here was that all the program leaders and members of the Industry Advisory Committee determined the productivity growth rate contributions of the programs, while the adoption profile values were validated internally by Sheep CRC management. Hence, there was wide consensus on the expected values of these variables.

Table 4.6. Summary of BCA assumptions

Variable	Unit	Value
Base year for onset of benefits		2008
Period of BCA simulation	years	20
Real discount rate	%	5
Probability of research success with the Sheep CRC[a]	%	80
Probability of research success without the Sheep CRC[a]	%	75

[3] It was recognised that this constraint could lead to bias in the economic surplus change (benefit) estimates because an increase in the production of one product usually leads to an increase in the production of the other. Whilst such changes for separate products have typically been added up to derive a total change, there is recent evidence that this practice will almost certainly underestimate the total changes (and the benefits) unless the cross-commodity interactions are properly taken account of using endogenous cross-price elasticities (Zhao *et al.* 2005). As this was not possible using the DREAM model, the benefit estimates can be considered to be conservative.

Research and development lags for programs	years	see Table 3.9
Adoption lags for programs	years	see Table 3.9
Adoption ceilings for programs	%	see Table 3.9
Research and development lags for projects	years	see Table 3.9
Adoption lags for projects	years	see Table 3.9
Adoption ceilings for projects	%	see Table 3.9
Price linkages (L) between regions (0<L<1) [a]	%	0.8

[a] used in the DREAM modelling – a parameter which measures how easily price changes in one region are transmitted to other regions.

Also, the outcomes on a program basis were likely to be more certain because successful projects within the programs could compensate for those that were not.

Table 4.7. Equilibrium price and quantity data

Region	Quantity produced (Kt)		Quantity consumed (Kt)		Weighted average price ($/t)	
	Wool	**sheepmeat**	**wool**	**sheepmeat**	**wool**	**sheepmeat**
Australia	669.0	617.2	17.9	312.4	7,000.0	3,300.0
China	280.7	1,715.1	328.7	2,223.5		
European Union	176.7	1,480.3	345.8	1,900.6		
New Zealand	255.7	530.6	23.3	69.3		
Rest of the world	1,016.3	3,090.1	1,682.7	2,927.5		

5-year averages from 1999; main source is ABARE (2004a).

Table 4.8. Medium-term own-price supply (ε) and demand (η) elasticities for sheep products

	Supply	Source	Demand	Source
National				
Australia wool	0.90	Sinden *et al.* (2004)	-1.40	Sinden *et al.* (2004)
Australia lamb	1.38	Sinden *et al.* (2004)	-1.54	Vere *et al.* (2000)
Australia mutton	1.38	Sinden *et al.* (2004)	-1.40	Sinden *et al.* (2004)
New Zealand wool	0.33	NZIER (2003)	-1.11	MAF (1993)
New Zealand lamb	0.75	estimate [a]	-0.63	MAF (1993)
New Zealand mutton	0.75	estimate [a]	-0.61	MAF (1993)
EU wool	0.50	estimate [a]	-0.24	Vere *et al.* (2000)
EU lamb	0.67	SAC (2000)	-2.19	Hanrahan (2000)
EU mutton	0.42	SAC (2000)	-2.19	Hanrahan (2000)
China wool	0.25	estimate [a]	-0.33	Pan *et al.* (2004)
China lamb	0.30	Shaw *et al.* (1997)	-0.60	Cai *et al.* (1998)
China mutton	0.30	Shaw *et al.* (1997)	-0.46	Ma *et al.* (2003)
ROW wool	0.80	CIE (2001b)	-0.35	Vere *et al.* (2000)
ROW lamb	1.0	estimate [a]	-0.50	estimate [a]
ROW mutton	1.0	estimate [a]	-0.31	Vere *et al.* (2000)

[a] authors' estimate based on review of other published estimates and knowledge of industry status in the different regions; the retail demand elasticities from the published studies were scaled according to the farm-retail price ratios to reflect the production level context of the evaluations.

The steps in this 'bottom-up' modelling process are illustrated in Figure 3.4. One difference from the 'top-down' model is that the supply shifts were calculated from a production systems model in which the differences in production costs with and without the project's technology were calculated. Another difference is that a stochastic simulation routine was used to make the economic surplus-welfare change calculations (but also using equations 1 to 6) in which the uncertainty about the likely size of the supply shift and adoption parameters was incorporated by imposing probability distributions on the values of those variables. Otherwise, the same benefit-cost procedures and assumptions were followed. Most of the input data for the 'bottom-up' modelling concerning the supply shifts-production cost differences, research lags and the values of the adoption variables were sourced from the information supplied by the project leaders for analysis within a spreadsheet-based model developed by Rendell-McGuckian management consultants. This model has been used by sheep industry research managers to evaluate new project proposals and was similarly used by the Sheep CRC as a project monitoring mechanism.

Other evaluation considerations

Supply shift calculations. The main economic impact of the Sheep CRC's production research is on the supply side of the industry. Hence, the size of the shift in supply from new technology adoption has a critical influence on the level of industry benefits from that research. This factor is commonly referred to as the *K* shift that comprises the effects of changes in both yields and production costs. A yield increase will translate into an equivalent, proportional outward shift of the industry's supply curve in the quantity direction; this is the *J-shift* component where $dY/Y = J$. The *K-shift* is a measure of the percentage shift down the supply curve in the price direction where the technology generates a reduction in unit production costs, and is linked by the supply elasticity (ε), where $K = J/\varepsilon$ (Alston *et al.* 1995). This shift is given by the vertical distance *ab* between the two supply curves in Figure 3.1.

Accurately measuring the supply shift is a most important part of the evaluation process. When evaluating individual projects, *K* is typically measured from the difference in the unit production costs with and without the new technology and expressed as a proportion of the farm price for the product to give a proportional supply shift measure. Some type of production budget or production systems model would normally be used to make this calculation. Under the 'top-down' approach, the supply shift has to be calculated on a program basis and this cannot be done using a farm-level model. Therefore, these calculations were made using the information in Tables 4.2, 4.3 and 4.4. The *K*-shifts for the individual projects were calculated from sheep production budget information supplied by the project leaders for the Rendell-McGuckian modelling.

The totals in Table 4.5 are the program components of the potential rate of productivity growth or the supply shift estimates for the economic surplus changes. These estimates represent the cost savings that could be realised from the adoption of the programs' technologies. With the Sheep CRC, the estimated savings were a 3.04 per cent reduction in the cost of producing Australian wool, a 0.33 per cent increase in the demand for Australian wool in all markets, a 3.34 per cent decrease in the cost of sheepmeat production in Australia, and a 0.8 per cent increase in the demand for sheepmeats in Australia's domestic and export markets. These cost savings-supply shifts were larger than the corresponding estimates for the *without*-Sheep CRC scenario, given the overall higher assumed rate of productivity improvement.

Expected adoption profiles for the Sheep CRC's research outcomes. Where new technologies result in improvements in management practices, input qualities and resources, their adoption generates economic benefits by increasing industry productivity relative to that which could be achieved from the existing technology stock (Marshall and Brennan 2001). The extent and time profiles for the adoption of a new technology in an industry are critical factors in determining benefit levels. The components of these profiles are the delivery time for the technology (the R&D lag), the time taken to achieve the expected level of adoption of the technology in the industry following its release (the adoption lag), and the eventual level of the technology's adoption in the industry (the adoption ceiling). The first two components define the total technology lag from the commencement of the research and the adoption of its outcomes by the industry, while the third defines the maximum number of operators who make up the size of the market that will potentially benefit from the research outcomes. Each component is a central issue in the economic evaluation of new technology introduction.

Adoption profiles are closely linked to the process of diffusion that concerns new technology adoption by populations of adopters rather than by individual adopters. For agricultural technologies, the speed of their diffusion is a major factor in the realisation of the potential benefits (Lindner 1986). The effect of reducing the total R&D lag is to advance the realisation of the benefits. Larger benefit streams result from more rapid technology adoption because the early period discounted (or real) values are larger than those in later periods, i.e. bringing forward the onset of the benefits results in larger benefits in real terms. This effect is illustrated in Figure 4.2(a). Two benefit profiles are nominally the same with curves that have the same shape and same slopes and thus have the same rate of adoption. The difference is the total R&D lag where the shorter lag enables the more rapid attainment of the adoption ceiling and a higher level of discounted benefits. In the case of Figure 4.2(b) the benefit profiles have the same R&D lag but different adoption rates and so the curves have different slopes. The shorter adoption lag that is indicated by the steeper slope of the benefit profile results in a more rapid attainment of the adoption ceiling and a larger level of discounted benefit.

Defining realistic adoption lags and levels is an important issue in *ex ante* evaluations where there may be no precedents to guide these definitions. Irrespective of the form that the adoption profile takes (either linear or logistic), this part of the evaluation process is the least supported by actual observations which means that adoption parameter values have to be elicited from within the research program. Information derived from the Rendell-McGuckian model was used to make the adoption estimates for the *with*-Sheep *CRC* scenario. Part of this model formalises the adoption expectations of the program leaders through a series of questions about the expected adoption profiles and the factors that may encourage the adoption of their program's outcomes. Those estimates are then matched against industry data derived from ABARE's farm surveys to derive industry sector adoption estimates that are adjusted according to internal assumptions in the model. A summary of the program adoption assumptions is given in Table 4.9. The values for the *with*-Sheep CRC scenario were derived as averages of the results of this modelling and subsequent validation by the program leaders. These estimates are for the individual programs (as used in the 'top-down' evaluations) and are entirely consistent with the previous studies that were reviewed. They range between a 30 per cent adoption ceiling for Sub-program 1.1 to adoption ceilings of 10 per cent for Sub-program 1.5 and Program 2. All adoption ceiling estimates were rounded to the nearest 5 per cent.

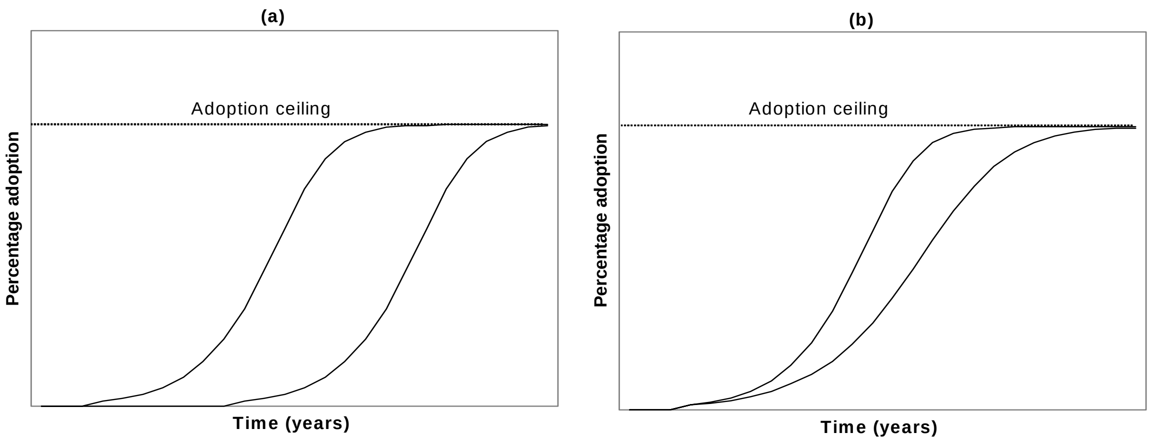

Figure 4.2. Effects of adoption profiles on industry benefits (source: Vere *et al.* 2004)

For the *with*-Sheep CRC scenario, it was assumed that the main effect of the Sheep CRC's research on the adoption profile was to expedite the delivery of the programs' technology areas and to shorten both the adoption lags by three years and the R&D lags by three years (as this was the average time period of many of the projects). This research was also assumed to have increased the adoption ceiling. Since 2001-02, the Sheep CRC has allocated an average 20 per cent of its annual funding to the Implementing Innovation Program 3 and the Education and Training Program 4. This funding represents a large investment in adoption enhancement that was assumed to have resulted in a proportional increase in the adoption ceilings for each of the research areas.

Corresponding estimates for the *without*-Sheep CRC scenario are also given in Table 4.9, where the R&D and adoption lags were lengthened by three years and the adoption ceilings were 80 per cent of the ceilings for the *with*-Sheep CRC scenario for the research areas in Program 1. The adoption value differences were larger (5 years) for Program 2 to recognise that this research would be unlikely to have been undertaken in the medium to longer term without the Sheep CRC.

All research program costs for the *with*-Sheep CRC scenario were derived from the Sheep CRC's accounts and are detailed in Table B1 (Appendix B). These costs include the Sheep CRC program allocations plus the value of the in-kind contributions made by the Sheep CRC's partners. Each program was required to allocate a proportion of the annual allocation from the Sheep CRC to extension and promotion (Table 4.10). Table 4.11 contains the proportions of total costs that were allocated to the six scientific program areas.

Table 4.9. Adoption profile values: program leaders' estimates

	With-Sheep CRC [a]			*Without*-Sheep CRC		
	R&D lag (years)	**Adoption ceiling (%)**	**Adoption lag (years)**	**R&D lag (years)**	**Adoption ceiling (%)**	**Adoption lag (years)**
Program area						
Genetics	4	30	4	7	24	7
Wool science	2	15	3	5	12	6
Meat science	4	20	2	7	16	5
Parasites	4	20	3	7	16	5
Nutrition	3	10	3	6	8	6
IAM	3	10	5	8	8	10

[a] base unadjusted values determined by the Rendell McGuckian model; adoption ceiling values with the Sheep CRC are averages of estimates rounded to nearest 5 per cent

Costs for the evaluations of Programs 1 and 2 were identified as being both research and extension and were allocated over the component research areas according to the proportional wool and meat supply and demand impacts given in Table 4.4. The costs of Programs 3, 4 and 5 were similarly allocated for the aggregate BCA of the Sheep CRC's total investment expenditure (no benefits were estimated for these programs).

Costs for the *without*-Sheep CRC scenario were held to be 80 per cent of the total value of the in-kind contributions made by the Sheep CRC's partners. After the approach of Griffith *et al.* (2004) on this issue, the 80 per cent scaling was considered to be a reasonable approximation of the value of the research funding that was likely to have continued to be made in the absence of the Sheep CRC. All costs for the *with*- and *without*-Sheep CRC scenarios used in the economic modelling are summarised in Tables B1 and B2 in Appendix B. All values involved in the evaluations were defined in real terms.

Table 4.10. Proportions of program budgets allocated to extension and promotion (%)

	2001-02	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**
Program area							
Genetics	0	0	5	5	5	5	5
Wool science	0	0	15	5	15	10	10
Meat science	0	0	5	10	10	15	5
Parasites	0	0	0	5	15	60	25
Nutrition	0	0	5	10	10	15	5
IAM	0	5	5	10	15	20	20

Estimates by program leaders rounded to nearest 5 per cent

Table 4.11. Proportions of total costs by program (%)

	2001-02	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**
Program area							
Program 1	63.5	65.4	63.2	60.3	53.7	58.3	56.1
Program 2	2.1	10.3	18.1	11.5	14.8	16.4	16.3
Program 3	9.0	9.4	6.2	5.8	7.7	7.4	7.4
Program 4	4.2	7.1	8.1	18.6	18.8	11.7	12.0
Program 5	21.3	7.8	4.4	3.7	5.1	6.1	8.3
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

It is reemphasised that the main purpose of these evaluations has been to measure the incremental economic benefits to public and industry stakeholders that could result from the Sheep CRC's research. Benefits are necessarily incremental because of the long history of research investments in the sheep industry, much of which has been in areas that are similar to the Sheep CRC's programs, and so there have been past and will be future benefits from these other programs. The estimated benefits from the Sheep CRC's research programs are therefore net of the expected benefit from other research that it is assumed would continue to be funded in the absence of the Sheep CRC.

Accommodating uncertainty in the individual 'bottom-up' project evaluations. Apart from the impact of new technologies on the supply of wool and sheepmeats as measured by the supply shifts, the expected benefits from the Sheep CRC's programs are most influenced by the timing and level of adoption of the research outcomes. While the values for these factors were based on the best available information from the programs, they remained uncertain because they had not been measured as they would have been under an *ex post* evaluation. In the individual 'bottom-up' project valuations, the effect of uncertainty was incorporated in the assessments by treating the supply shifts and the adoption expectations as random variables with value ranges that were simulated within probability distributions following stochastic Monte Carlo procedures. Simulation models were developed in which the supply shifts, the R&D and adoption lags and the adoption ceilings were stochastically simulated in calculating the economic surplus changes from the adoption of the Sheep CRC's technologies.

This procedure enabled the expected benefits to the projects to be estimated within the ranges of the defined probability distributions, and overcame the problem of using single values for variables that were likely to be uncertain because of the *ex ante* nature of the evaluations. Triangular probability distributions represent the random values of the variables that are given in Table 4.12, where these distributions are specified by a minimum, a median (most likely) and a maximum value. The median values of the probability distributions for the *with*-Sheep CRC scenario were taken to be the program leaders' estimates from their Rendell-McGuckian modelling for the projects. The maximum and minimum values were ±20 per cent of the median values. The corresponding median values of the probability distributions for the *without*-Sheep CRC scenario were derived by adjusting the *with*-Sheep CRC adoption ceilings by two-thirds, and adding five years to the research and adoption lag (here, this lag difference for the individual projects was longer than for the full program).

This stochastic simulation process is based on sampling from probability distributions for a large number of iterations. The main outputs were the cumulative distribution functions (CDFs) for the range of values for the NPVs and BCRs. These functions indicated the probabilities of a particular research program resulting in a benefit-cost outcome of a given value. The minimum and maximum values of the simulations are not reported as they are the outlier values with very low probabilities of being realised. Consequently, the 5^{th} and 95^{th} percentiles are taken to respectively represent the lower and upper values from the NPV and BCR simulations. The median values is given by the 50^{th} percentile to represent the most likely result (i.e. the benefit-cost outcome that a project is most likely to deliver given the range of values specified in the probability distributions).

Table 4.12. Probability distributions for the random variables

	Triangular distribution parameters					
	***With*-Sheep CRC**			***Without*-Sheep CRC**		
	Minimum	**Median**	**Maximum**	**Minimum**	**Median**	**Maximum**
Adoption ceilings (%)						
Project 1.1.1	39.2	49	58.8	25.6	32	38.4
Project 1.2.6	8.8	11	13.2	5.6	8	7.2
Project 1.3.5	20.8	26	31	13.6	17	20.4
Project 1.4.5	10.4	13	15.6	7.2	9	10.8
Project 1.5.1	9.6	12	14.4	6.4	8	9.6
Project 2.3.1	8	10	12	6.4	8	9.6
Total research and adoption lag (years)						
Project 1.1.1	5.6	7	8.4	9.6	12	14.4
Project 1.2.6	4.8	6	7.2	8.8	11	13.2
Project 1.3.5	4.8	6	7.2	8.8	11	13.2
Project 1.4.5	2.4	3	3.6	6.4	8	9.6
Project 1.5.1	3.2	4	4.8	7.2	9	10.8
Project 2.3.1	4	5	6	8	10	12

Median values

5. Results

The four sets of results of the Programs 1 and 2 evaluations are given in five tables. To facilitate the interpretation of these results, their links and the methods and data from which they were derived are given in four parts.

- Part 1 contains the benefit-cost estimates for the six program areas that were separately calculated for the *with*- and *without*-Sheep CRC scenarios using the 'top-down' method developed by the Allen Consulting Group (2003). Calculations were made using the DREAM model. These calculations were based on the program productivity growth contribution data that were derived from the program leaders with inputs from the Industry Advisory Committee (Tables 4.2 and 4.3), and the adoption ceiling and lag values (Table 4.9) derived from the Rendell-McGuckian modelling that was done independently by Sheep CRC management. All input data were specific to the individual programs and their areas of industry impact.

- Based on the same 'top-down' procedures and data that were used to derive the Part 1 results, Part 2 is a summary of the Part 1 results that indicates the net benefit-cost outcomes, by program and area of impact, which could be attributed to the Sheep CRC's research investment. These results can be considered to be the main economic outcomes of the evaluation process for the programs.

- Part 3 is a regional disaggregation of the Part 2 program-level results that indicates the shares of the net benefits that could flow to Australian and international producers and consumers of sheep products. This indication of the likely distribution of the net benefits is necessary to demonstrate the potential industry impacts of the Sheep CRC's research programs. There are slight differences in the total net NPV estimates in Parts 2 and 3 because the Part 3 results used average values of the adoption variables whereas specific adoption values were used to evaluate the individual programs in the Part 2 results.

- Part 4 contains the benefit-cost estimates of the six selected projects from Programs 1 and 2. Based on a 'bottom-up' method, these estimates were made using a stochastic benefit-cost model (Appendix C) and input data values for production cost differences (the supply shifts) and the adoption and lag values for the individual projects that were derived from the Rendell-McGuckian modelling done by management. These project level results differ from those for the programs since they were derived from a stochastic model in which the values of the supply shifts and adoption variables were simulated within the bounds of defined probability distributions (Table 4.12) to account for the higher degree of uncertainty that was likely to surround the values of the input data for the projects. These results are given in terms of their maximum, most likely and minimum benefit-cost outcomes. Cumulative distribution functions are also given to indicate the likelihood of a project delivering a particular benefit-cost outcome.

The main links between the 'top-down' method evaluations of the programs and the 'bottom-up' method evaluations of the projects is that both utilise estimates made by the program leaders about the likely impacts of their research on productivity growth, as well as the adoption and lag assumptions derived from the management's Rendell-McGuckian modelling. Both methods deliver similar information about the potential incremental benefits of the Sheep CRC's investment. Their separate program and project focuses follow the recommendations of the Allen Consulting Group (2003) that were considered to be most valid in this research evaluation context. Tables 5.1, 5.2 and 5.3 contain the results of the 'top-down' program evaluations, while Tables 5.4 and 5.5 contain the results of the 'bottom-up' project evaluations.

5.1 Program BCAs by program area

Table 5.1 contains the results of the BCAs for the individual programs by area of impact that were estimated using the DREAM model. These are the estimates of the potential returns to each program by impact area for the *with*- and *without*-Sheep CRC scenarios. The individual NPVs are the differences between the present values of the benefits and costs over the 20-year BCA period. The individual BCRs are then calculated from these differences.

Table 5.1. BCA outcomes for Sheep CRC research in Programs 1 and 2[a]

	***With*-Sheep CRC**				***Without*-Sheep CRC**			
Program area	**PV benefits ($m.)**	**PV costs ($m.)**	**NPV ($m.)**	**BCR ($:1)**	**PV benefits ($m.)**	**PV costs ($m.)**	**NPV ($m.)**	**BCR ($:1)**
Genetics								
wool supply	78.303	6.087	72.216	12.9	25.901	3.587	22.314	7.2
meat supply	14.475	2.609	11.866	5.5	7.762	1.575	3.187	3.0
Wool science								
wool supply	23.149	5.087	18.062	4.6	8.621	2.645	5.976	3.3
wool demand	33.694	3.357	30.337	10.0	15.556	1.756	13.800	8.8
meat supply	3.483	1.729	1.754	2.0	1.099	0.900	0.199	1.2
Meat science								
meat supply	20.985	5.780	15.205	3.6	7.263	2.839	4.424	2.6
meat demand	37.336	5.870	31.556	6.5	15.641	2.839	12.801	5.5
Parasites								
wool supply	54.521	6.420	48.101	8.5	16.516	3.555	12.961	4.6
wool demand	5.800	0.332	5.468	17.5	2.140	0.184	1.956	11.6
meat supply	15.871	4.317	11.554	3.7	5.394	2.390	3.004	2.3
Nutrition								
wool supply	5.911	1.637	4.273	3.6	2.027	0.999	1.028	2.0
meat supply	10.343	6.551	3.792	1.6	3.571	3.995	-0.424	0.9
IAM								
wool supply	20.544	5.849	14.695	3.5	4.493	3.416	4.594	1.3
meat supply	9.255	5.811	3.444	1.6	2.283	3.555	-1.272	0.64

[a] benefits and costs are discounted at 5 per cent real over 20 years using the DREAM model.

The program estimates indicate that the Sheep CRC has the potential to deliver significant economic benefits to the Australian sheep industry. Under the *with*-Sheep CRC scenario (left hand columns of Table 5.1), the NPVs range from $72.2 million for genetics research that improves the supply of wool to $1.7 million from research that impacts on sheepmeat supply under Program 1.2, when summed over the 20-year period of the benefit-cost simulation. The range of the BCRs is from 17.5:1 for research into parasite management that impacts on wool demand to 1.6:1 for nutritional research that affects the supply of sheepmeats. The NPV and BCR top rankings for these programs differ because of the low costs for the parasite management project relative to the costs of the genetics program, although the latter program could generate a much larger NPV[4]. All programs generate positive NPVs and BCRs that are greater than unity.

Equivalent results for the *without*-CRC scenario are reported in the right hand columns of Table 5.1. All the NPVs and BCRs are smaller, some substantially so, and some NPVs are negative with corresponding BCRs less than one. The estimates for the *without*-Sheep CRC scenario indicate that lower levels of benefits were expected to flow from those same research areas if the Sheep CRC had not been funded.

5.2 Net BCAs by program area

Table 5.2 contains the estimates of the net potential benefits that the Sheep CRC could deliver in the research areas covered by Programs 1 and 2. These measures were calculated from the data in Table 5.1 and are the incremental benefits for each program area that are net of the benefits that could result from other research that is likely to be undertaken in these areas without the Sheep CRC. The incremental NPV ($191.3 million) is therefore the value of the total discounted benefits that could be attributed to the Sheep CRC's research investment in these programs, while the incremental BCR (8.06:1) is calculated as the ratio of the total present values of the benefits and costs. The incremental BCR can be interpreted as representing a return of approximately $8 for every $1 of the Sheep CRC's Commonwealth contribution, plus the additional resources this funding has leveraged from industry and research providers. All research areas therefore represent sound economic investments for the Sheep CRC.

The main contributors to the total incremental NPV are genetics research that affects the supply of wool ($49.9 million), improved parasite management in wool production ($35.1 million), and research that impacts on sheepmeat production ($29.5 million). The size of the total incremental benefit between the *with*- and *without*-Sheep CRC scenarios results from the differences in the expected impacts of the program research areas on productivity growth in the sheep industry (as estimated by the program leaders and validated by the Industry Advisory Committee), from the differences in the expected adoption profiles for the programs' technologies (as derived from the Rendell-McGuckian modelling for the *with*-Sheep CRC scenario), and from differences in the costs of research between *with*- and *without*-Sheep CRC scenarios where the costs for the latter program were taken to be 80 per cent of the value of the in-kind contributions to the Sheep CRC.

Table 5.2. Net BCA outcomes for Sheep CRC Programs 1 and 2

Program area	PV benefits ($m.)	PV costs ($m.)	NPV ($m.)	BCR ($:1)
Genetics				
wool supply	52.402	2.500	49.902	
meat supply	9.713	1.034	8.679	
	62.115	3.534	58.581	
Wool science				
wool supply	14.528	2.442	12.086	
wool demand	18.138	1.601	16.537	
meat supply	2.384	0.829	1.555	
	35.050	4.872	30.178	

[4] Note that NPV is usually preferred as the single BCA criterion for comparing programs and projects. The BCR can give incorrect rankings if programs and projects differ in size and in costs, in particular.

Meat science				
meat supply	13.722	2.941	10.781	
meat demand	21.696	2.941	18.755	
	35.418	5.882	29.536	
Parasites				
wool supply	38.005	2.865	35.140	
wool demand	3.661	0.148	3.512	
meat supply	10.477	1.927	8.551	
	52.143	4.940	47.203	
Nutrition				
wool supply	3.883	0.638	3.245	
meat supply	6.772	2.556	4.216	
	10.655	3.194	7.461	
IAM				
wool supply	16.051	2.433	13.618	
meat supply	6.972	2.256	4.716	
	23.023	4.689	18.334	
Total net outcome	**218.403**	**27.111**	**191.292**	**8.06**

[a] discounted at 5 per cent real over 20 years; [b] calculated as the ratio of the total present values of benefits and present values of costs, not the differences between the individual BCRs.

5.3 Program BCAs by region and industry group

Table 5.3 contains the regional disaggregation of the NPVs of the net economic surplus changes for the four broad impact areas of the six programs. These changes were estimated using the total supply shifts given in Table 4.5. They are close to, but are not identical to the net benefit estimates in Table 5.2 because they were derived from average values of the adoption variables, whereas the estimates for the separate program impacts incorporated specific adoption values. The disaggregated estimates are included to indicate the general distribution of benefits between producers and consumers and regions that typically result from new technologies in competitive agricultural industries.

These results are consistent with the theory of regionally-disaggregated economic surplus measurement wherein the adoption of a supply-increasing or cost-reducing technology in one region benefits producers in that region, while producers in other regions who are unable to adopt the technology and lower production costs incur welfare losses from the decreased price. Hence, Australian sheep producers gained a net benefit from the Sheep CRC's research programs with a NPV of $140.5 million because they could directly access the new technologies. Most of this benefit came from the research impacts on wool and sheepmeat production. Sheep product consumers in all regions gained from the lower product prices that followed the supply increases. Sheep producers in the four international regions lost economic surplus valued at $113.6 million from the price spillovers which could not be compensated for by production cost savings from the new technologies. However, this loss was offset by a $160.5 million gain to consumers from greater access to lower priced wool and sheepmeat in those regions. Product enhancing research can be expected to increase demand and market prices, which in this case resulted in relatively small gains to producers and similarly small consumer gains in most instances. Overall, Australian sheep producers and consumers gained about three-quarters of the total net benefits from the Sheep CRC's research.

The benefit shares are also consistent with the market elasticity conditions. Producers benefit most when supply is inelastic and demand is elastic, while consumers benefit most under the converse elasticities. These conditions relate to most of Australia's major livestock commodities. Thus, Australian sheep producers have been estimated to derive the largest share of the benefits from the Sheep CRC's research (about 70 per cent).

Table 5.3: Regional disaggregation of net total benefits to Sheep CRC research

	NPVs of net economic surplus changes ($m.)				
Program impact area	**Wool supply**	**Wool demand**	**Meat supply**	**Meat demand**	**Total**
Australian producer	83.133	2.948	49.469	4.900	140.450
Australian consumer	0.738	0.269	2.752	7.464	11.223
China producer	-11.557	1.237	-15.103	2.503	-22.920
China consumer	13.539	1.309	19.584	6.125	40.557
EU producer	-7.275	0.779	-13.034	2.160	-17.370
EU consumer	14.243	1.072	16.742	-2.774	29.283
New Zealand producer	-10.528	1.126	-4.672	0.774	-13.300
New Zealand consumer	0.959	-0.103	0.611	-0.101	1.366
ROW producer	-41.833	4.479	-27.209	4.510	-60.055
ROW consumer	50.312	14.590	19.786	4.566	89.254
Totals	91.681	27.706	48.926	30.127	198.488

This total NPV varies slightly from the estimate in Table 4.2 because it was based on average values of the adoption variables.

5.4 Project BCAs

The results of the stochastic 20-year benefit-cost analyses (Table 5.4) indicate that the selected projects from the six areas of Programs 1 and 2 have the potential to generate significant levels of economic benefits over the range of expectations about the adoption of those technologies in the Australian sheep industry. The NPV and BCR estimates are the simulated differences between the *with*- and *without*-Sheep CRC scenarios over the ranges of the probability distributions for the adoption variables defined in Table 4.12 for the projects. They represent the incremental benefits to those research areas that could be attributed to the Sheep CRC.

Positive net benefits result because the Sheep CRC's investment has expedited the delivery of the improved technologies in the project areas and has improved the adoption of those technologies by sheep producers. The potential benefits under the *with*-Sheep CRC scenarios are larger than the *without*- scenarios because these benefits occur earlier in the benefit-cost period at higher adoption levels and are less reduced by the discounting.

Table 5.4. Stochastic 20-year BCA results for selected Sheep CRC projects: estimates of incremental benefits attributable to projects

	95th percentile		**50th percentile**		**5th percentile**	
	NPV ($m.)	**BCR ($:1)**	**NPV ($m.)**	**BCR ($:1)**	**NPV ($m.)**	**BCR ($:1)**
Project 1.1.1	27.42	6.38	15.75	3.40	7.93	1.40
Project 1.2.6	46.15	14.27	28.22	8.25	15.04	3.95
Project 1.3.5	29.99	8.53	17.85	4.47	9.26	1.71
Project 1.4.5	71.34	57.52	40.11	22.46	19.42	1.54
Project 1.5.1	38.15	13.02	23.39	7.40	12.44	3.58
Project 2.3.1	113.54	25.56	68.49	10.32	35.97	1.01

The median NPVs of the incremental benefits range between $15.75 million for Project 1.1.1 (Genetic Analysis of Sheep Production Traits) to $68.49 million for Project 2.3.1 (On-farm Implementation Trials), and the incremental BCRs range from 3.4:1 for Project 1.1.1 to 22.5:1 for Project 1.4.5 (On-line Sheep Worm Management). The percentile results show the spread in the values of the benefit-cost criteria when estimated from the 10,000 iterations of the simulation models. All NPVs calculated at the 5th percentile are positive and all BCRs at that percentile are greater than one. It should be recognised that these stochastic BCA results for the individual projects are based on the actual project costs, whereas the program BCAs incorporate the costs of Programs 3, 4 and 5. The program estimates are therefore adversely affected by the additional program costs, although it is likely that these non-evaluated programs are necessary to realise the benefits from Programs 1 and 2.

Tables 5.5 and 5.6 contain the simulated cumulative distribution function (CDF) results that indicate the probabilities of the projects delivering a particular incremental benefit-cost outcome based on the benefit-cost differences between the *with*- and *without*-Sheep CRC scenarios. While the maximum and minimum percentiles are the extreme values of the simulations with low probabilities of occurrence, these results indicate that there is zero probability that any project could deliver a negative NPV or a BCR less than unity. Hence, there was zero probability that any of the projects will deliver a negative incremental return. A useful way to consider these CDF estimates is to set an acceptable benefit-cost outcome from a project. For the genetics project 1.1.1 there is a 90 per cent probability that it will generate NPV of at least $7.9 million over the 20-year period, where NPV = 0 is the break-even return on a research investment, and a similar probability that Project 2.3.1 will generate a BCR greater than 1. The median NPV and BCR values represented by the 50th percentile, represent the most likely result (i.e. at least a 50 per cent probability of obtaining it).

The large differences in the BCA estimates between the projects are the result of differences in the project costs and in the impact of the technologies on production costs and product yields. Project 1.4.5 costs averaged only 5 per cent of the total costs of the six projects over the seven-year funding period, and produced a relatively large 1 per cent composite shift in sheepmeat production. Similarly, the costs of Project 2.3.1 averaged 16 per cent of the total costs of the six projects and generated 1 per cent and 0.5 per cent shifts in sheep meat and wool production. Hence, these projects have the potential to deliver large levels of benefits at relatively low cost.

Table 5.5. CDFs of the incremental benefits over 20 years – NPVs ($ millions)

	Sheep CRC projects					
	1.1.1	**1.2.6**	**1.3.5**	**1.4.5**	**1.5.1**	**2.3.1**
5%	7.93	15.04	9.26	19.42	12.44	35.97
10%	9.28	17.25	10.72	22.98	14.39	41.45
15%	10.23	18.96	11.85	25.59	15.85	45.53
20%	11.13	20.56	12.84	28.02	17.03	49.54
25%	12.00	21.96	13.72	30.05	18.19	53.02
30%	12.78	23.24	14.51	31.95	19.35	56.59
35%	13.58	24.50	15.34	33.91	20.44	59.39
40%	14.31	25.74	16.15	36.15	21.50	62.44
45%	14.99	26.86	16.99	38.05	22.46	65.49
50%	15.75	28.22	17.85	40.11	23.39	68.49
55%	16.53	29.55	18.65	42.06	24.45	71.54
60%	17.35	30.78	19.55	44.37	25.53	74.67
65%	18.21	32.08	20.39	46.61	26.61	78.29

70%	19.13	33.53	21.34	49.24	27.92	81.94
75%	20.16	35.09	22.42	52.24	29.26	85.87
80%	21.38	37.01	23.68	55.41	30.71	90.12
85%	22.89	39.17	25.12	59.07	32.49	95.87
90%	24.70	41.88	27.05	63.70	34.73	103.16
95%	27.42	46.15	29.99	71.34	38.15	113.54

Table 5.6. CDFs of the incremental benefits over 20 years – BCRs ($:1)

	Sheep CRC projects					
	1.1.1	**1.2.6**	**1.3.5**	**1.4.5**	**1.5.1**	**2.3.1**
5%	1.40	3.95	1.71	1.54	3.58	1.01
10%	1.74	4.67	2.20	1.54	4.23	1.83
15%	2.02	5.25	2.54	3.11	4.72	3.54
20%	2.21	5.74	2.85	5.38	5.14	4.74
25%	2.43	6.18	3.15	6.83	5.53	5.65
30%	2.64	6.61	3.40	13.12	5.93	6.55
35%	2.82	7.02	3.67	16.16	6.32	7.44
40%	3.03	7.43	3.94	18.63	6.66	8.40
45%	3.22	7.84	4.20	20.71	7.03	9.32
50%	3.40	8.25	4.47	22.46	7.40	10.32
55%	3.60	8.66	4.74	24.03	7.79	11.37
60%	3.80	9.12	5.04	25.84	8.17	12.47
65%	4.01	9.57	5.33	27.75	8.60	13.63
70%	4.26	10.06	5.65	29.94	9.08	14.76
75%	4.52	10.63	6.00	32.54	9.62	16.08
80%	4.84	11.24	6.43	35.91	10.27	17.54
85%	5.21	11.95	6.94	41.99	10.91	19.23
90%	5.69	12.86	7.57	49.14	11.74	21.66
95%	6.38	14.27	8.53	57.52	13.02	25.56

5. Summary and Discussion

This report presents estimates of the industry economic benefits that are expected to result from the scientific research programs of the Sheep CRC. The Sheep CRC's research investment in the Australian sheep industry represents a continuation of longstanding research in some of the program areas, and other areas of largely new research. The benefits of the Sheep CRC's research were considered to result from the role of the programs and projects in expediting the development and release of improved technologies in the sheep industry. Because it has not been possible to determine the full costs of all sheep research that has been made by many Australian research institutions over time, the known research costs under the Sheep CRC programs, including the values of the in-kind contributions of the collaborating agencies, were used to estimate the changes in benefits that could result from that research under a range of industry impact and adoption assumptions.

The emphasis in this evaluation has been to determine the potential economic impact of the Sheep CRC's scientific research on the Australian and international sheep industries, focussing on the scientific research areas in Programs 1 and 2. The high level of public funding in the Sheep CRC has highlighted the need to demonstrate the benefits to all stakeholders from this investment. Those stakeholders include Australian taxpayers. It has been appropriate to adopt a partial equilibrium-sheep industry context to address that accountability requirement. This is because a full industry benefit that includes shares to consumers cannot be properly evaluated by estimating the benefits of new technology adoption at a farm or production system level and then extrapolating those changes across all production systems to determine an aggregate benefit. Evaluations at the farm or production system levels assume that prices are not affected by changes in resource allocation or product mix from new technology adoption, and so all benefits are captured by producers. This may be realistic for a single system wherein production changes do not affect market price, but if new technologies are widely adopted, the aggregate change in output across all systems can be expected to alter commodity prices, and so affect the welfare of producers and consumers.

Since the objectives of rural research mainly concern the distribution of welfare between social groups, widespread technology adoption in competitive industries should increase commodity supplies and reduce prices to generate welfare gains. A commonly used method for evaluating the economic welfare effects of agricultural research problems follows the concept of economic surplus. The basis of economic surplus as a welfare measure is that the product's supply price represents its unit value to producers and the demand price represents its unit value to consumers. In this evaluation, the benefits to the Sheep CRC's research were estimated in terms of the changes in economic surplus or welfare that could result from the adoption of improved technologies by a larger number of wool and sheepmeat producers. Because of Australia's strong role in international sheep markets, the impacts of the Sheep CRC's research on sheep producers and consumers in other countries have also been considered.

The evaluation comprised estimates of the potential benefits to the six major research areas in Programs 1 and 2, and to a project selected by the program leaders from each of those areas following the defined *with*- and *without*-Sheep CRC scenarios. Following the approach adopted by the Allen Consulting Group (2003), the programs were evaluated using a 'top-down' method while the projects were evaluated using a 'bottom-up' method. Under both methods, the main input data required by the models were derived from the program leaders and from the Rendell-McGuckian modelling that was undertaken by Sheep CRC management. The program benefit-cost analysis was estimated over a 20-year period using a

5 per cent real discount rate using the DREAM model software. This is an internationally respected model for evaluating the benefits of agricultural research processes.

Over the six research program areas, the BCA estimates demonstrated the potential for the Sheep CRC to deliver significant economic benefits to the Australian sheep industry. These benefits resulted from an expected 2.5 per cent increase in sheep industry productivity from the Sheep CRC's activities, and from those activities generating a faster rate and higher level of technology adoption. When estimated in terms of their impacts on supply and demand for wool and sheepmeat, each of the program areas under the *with*-Sheep CRC scenario generated positive BCA values in comparison to the corresponding estimates for the *without*-Sheep CRC scenario. These estimates are the value of the total discounted benefits that could be attributed to the Sheep CRC's research investment in Programs 1 and 2.

Over the 20-year period, the total incremental benefit had a NPV of $191.3 million and a BCR of 8.1:1 that indicates that the Sheep CRC's research portfolio is expected to return about $8 for every $1 invested at the defined levels of technology adoption. They represent sound economic returns to the Sheep CRC's investment, particularly when it is considered that the cost side of the aggregate BCAs include the costs of the other three programs, although as previously indicated these programs are likely to be necessary to assist in realising the benefits from the scientific programs. A regional disaggregation of the total incremental benefit showed that Australian sheep producers and consumers gained about 75 per cent of this benefit, that sheep producers in other countries suffered welfare losses because they could not access the Sheep CRC's technologies, and that sheep product consumers in all countries gained from the lower product prices that followed supply increases.

It is useful to compare these broad orders of magnitude of program benefits with those estimated for the recent renewal of the CRC for Beef Genetic Technologies (Griffith *et al.* 2004, Griffith 2005). In that analysis, the incremental benefit from the extra investment and consequent research effort brought about by the Commonwealth funding was estimated to be worth over $1.4 billion in present value terms, far in excess of the marginal investment of about $40 million. Thus every $1 of extra resources brought into the Australian beef industry through funding the CRC for Beef Genetic Technologies, above that estimated to be made available through the *without*-CRC scenario, was expected to return around $35 to the industry.

These are much larger values than those reported in the current analysis. There are two main reasons for these differences. First, the beef industry has had the benefit of two previous successful CRCs that have instilled a greater awareness of the opportunities arising from technical change. Adoption levels of new technologies in the beef industry are higher than in the sheep industry, and it is likely that the current underlying rate of potential productivity growth is also higher (Griffith 2005). This generates actual or measured rates of productivity improvement for the beef industry that are markedly higher than those reported in Table 4.1. Further, the teamwork built up over the past 12 years and the explicit incorporation of enhanced adoption strategies suggest that the actual rate of productivity growth expected from the CRC for Beef Genetic Technologies should be somewhat higher again than from the Sheep CRC. Second, the beef industry is considerably larger than the sheep industry in value terms, and since productivity growth is measured in proportional terms, even similar rates of growth will produce larger benefits in large industries than in small industries.

A slightly different economic modelling approach was followed in evaluating the projects selected from the six program areas. This approach was based on the same theory and formulae as the DREAM model but utilised a stochastic simulation routine that allowed uncertainty about the values of the adoption variables for the *with-* and *without-*Sheep CRC scenarios to be explicitly incorporated in the BCAs (reasons for this uncertainty are given in Section 4). Again, these estimates were the incremental benefits to the research areas that could be attributed to the Sheep CRC, where the median values of the estimates were considered to be the most likely BCA outcomes for the projects as there was at least a 50 per cent probability of obtaining that result. The stochastic project evaluation results generally followed those for the programs. Each of the projects had the potential to generate sound net economic returns over the *without-*Sheep CRC scenarios, and there was zero probability of negative returns in any instance. Because the project evaluations did not include any costs from Programs 3, 4 and 5, they are not strictly comparable to the program-based estimates, and there were examples of high BCA outcomes where project costs were low and the supply shifts were relatively large. To complement the stochastic simulation evaluations, cumulative distribution functions were also estimated to indicate the probabilities of obtaining particular BCA outcomes for each project.

The main outcome of the evaluations of the science Programs 1 and 2 and the six selected projects from those programs is that the new production and marketing technologies developed by the Sheep CRC have the potential to deliver significant economic benefits over the long term. Introducing new technologies benefit sheep producers through the opportunities provided to reduce production costs, thereby increasing the rate of productivity growth in the sheep industry. Benefits also accrue to consumers through the delivery of improved sheep products at a reduced market price. These benefits have an estimated present value of $218.4 million compared to a $27.1 million present value cost of this research over the 20 year period.

It is recognised that it will be many years before the full set of benefits from some of the components of the Sheep CRC's research program will be realised, and there have been difficulties in quantifying all future benefit streams that could result from this research. Also, other areas of research investment that have not been quantified in financial terms clearly have the potential to deliver significant long-term benefits. Such benefits are evident from a benefit-cost analysis of the education Program 4 that was undertaken independently using the Rendell-McGuckian model. In that BCA, the value to the sheep industry of the future contributions of hundreds of postgraduates and undergraduates, thousands of Vocational, Education and Training (VET) students, wool classers and other industry personnel had a NPV of $132 million and a BCR of 22.7:1. Other important capacity building benefits will also result from the Sheep CRC's role in facilitating collaboration between scientists and institutions and in training young professionals to work in the sheep industry.

There are several aspects of the information that has gone into these evaluations that require comment. While the incremental BCA estimates to the programs and projects are positive in all instances, some are not overly large and probably do not reflect the benefit expectations of the Sheep CRC's researchers and managers. Where that has occurred, the main contributing factors are the adoption ceiling assumptions and the costs of the program and projects. The values of the adoption variables that were derived from the Rendell-McGuckian modelling that was undertaken by the program leaders and management are relatively low with the maximum program ceiling adoption level being 30 per cent (Genetics) while the nutrition and IAM programs anticipate only 10 per cent adoption ceilings. However, these seemingly low adoption expectations appear to be realistic and consistent with what is known about the limited uptake of new technologies in the livestock industries. Extension and education has been an important role of the Sheep CRC and this activity could be expected to improve the overall level of adoption of new technologies in the sheep industry over time. This explicit focus on industry take-up of the technologies generated by the programs should result in shorter lags in achieving results and in industry adopting them, and an overall higher level of industry adoption (Griffith 2005, Vere *et al*. 2003).

On the cost side, each of the programs has highly valued in-kind contributions relative to the Sheep CRC grants. This was particularly so in the early years where the in-kind costs were at least 84 per cent of the first-year (2001-02) total costs of each program and at least 60 per cent of the total program costs in the first three years. The average proportions of in-kind to total program costs over the seven years of funding are a minimum of 65 per cent for Sub-program 1.3 and a maximum of 75 per cent for Program 2. The average seven-year value of the in-kind costs over the six programs is 71 per cent. Such initial high costs have important discounting effects on the benefit estimates since each program's benefits start after a total lag of between five to eight years. It is not known how the in-kind contributions are valued by the contributing agencies nor if they are consistent between the agencies. The valuation of external contributions to research programs is recognised as being a major cost estimation problem in most economic R&D evaluations, not just for the Sheep CRC.

A further qualification concerns the definitions of the *with*- and *without*-Sheep CRC scenarios where it was assumed that there would have been some future level of research in each of the six program areas had the Sheep CRC not eventuated. Valuing the costs of any independent research (under the *without*-Sheep CRC scenario) at 80 per cent of the in-kind contributions to the Sheep CRC implies that this research would have eventually been undertaken to almost the same level as the Sheep CRC's programs. Although it is not possible to predict what future research levels might be, this presumption might be reasonable on a program basis in areas such as genetics, parasite management and nutrition that have been a longstanding research focus in the Australian sheep industry. It is less reasonable in other areas such as IAM and aspects of meat science where the program leaders consider that little comparable research would have been undertaken without the Sheep CRC. Should that be the case, it would be appropriate to use larger differences in the adoption variables and that would enhance the values of the incremental benefits to the Sheep CRC's research in those areas.

Finally, there are another set of economic benefits that have not been counted. The estimated benefits reported above refer to the broader Australian sheep industry (from sheep producers to wool, lamb and mutton consumers). Based on simulations with the updated MONASH model of the national economy (Wittwer 2003), calculations for the Australian beef industry suggest a benefit to the national economy of some 45 per cent above that for the beef industry alone. A multiplier of a similar magnitude should be broadly applicable to the sheep industry and to productivity shocks of different magnitudes, as in the *with*-Sheep CRC case, or to the net benefits between the two scenarios. For the incremental funding case reported in Table 4.2, this would imply an extra $86 million in benefits to the Australian economy, above and beyond the estimated benefits of $191.3 million accruing to the broader sheep industry.

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Appendix A: Structural Econometric Model of the Australian Sheep Industry.

An existing structural econometric model of the Australian sheep and wool industries also could have been used in evaluating the Sheep CRC's research programs. This model was developed to represent the supply, demand and price formation processes of the wool, lamb and mutton sectors of the sheep industry. The use of this type of model is consistent with the economic surplus methods described in Section 3.2, under which it is necessary to capture the full market effects that are expected to result from the adoption of a new production-increasing technology in the competitive sheep industries. These effects are the changes in supply, demand and prices that are expected to result when a new technology is widely adopted in an industry. An important feature of the econometric model is its ability to capture the high levels of seasonality that underlie the supply of and demand for Australian sheep products. Seasonality is evident in sheep production where pasture growth cycles strongly influence sheep breeding decisions. Also, there are biological constraints that result in time lags between breeding and product sales. These factors explain the price-inelastic nature of sheep production in the short to medium term. Seasonality is also found on the demand side of the Australian sheep industry because of quarterly changes in the flow of products onto the market.

Econometric models have previously been used for measuring the aggregate benefits from new technology adoption and their distribution over livestock industry sectors (Vere and Griffith 2004). Essentially, this type of model is a formal representation of the supply and demand sides of the sheep industry that are illustrated in the partial equilibrium economic surplus models in Figures 1 and 2. The main difference between the two models is that the latter model has a given initial market equilibrium and the supply shift and market parameters determine the new equilibrium price and quantity. Changes in economic surplus from technology adoption are measured as a shift away from the given equilibrium. Using the econometric model, new prices and quantities are predicted and economic surplus is measured as a shift towards the new equilibrium. An advantage of econometric simulation is that the dynamic responses to technology adoption can be traced out over time as the model solves period by period. This overcomes the major limitation of the economic surplus model where the static nature makes it difficult to take account of the time path of responses to technology adoption before a final equilibrium is achieved. In using this econometric model to simulate the effects of technology adoption in the sheep industry, the values of the market variables were altered, the model re-solved, and the results compared with the base model solution. Any changes in prices and quantities are assumed to be attributable to the imposed changes resulting from technology adoption. With the formulae in equations 1 to 6, these changes are converted into measures of economic surplus change which are allocated to producers and consumers according to the values of the supply and demand elasticities.

The structure of this econometric model is based on a set of equations that explain the determination of the values of the main industry variables and their linkages. These variables include sheep breeding decisions by type, wool and meat production, consumption and exports, and the farm, retail and export prices for sheep products. Each endogenous variable (i.e. a variable with values that are determined by the model) is represented by a separate equation that is either behavioural or definitional. There are 50 endogenous variables in the model that are represented by 28 behavioural equations and 22 definitional equations. The simultaneous-equations methodology on which this model is based is a well recognised and logical approach to estimating economic relationships where the values of two or more variables are jointly dependent. Econometric procedures were used to estimate and simulate the model using long series of historical sheep industry data covering the period 1970:1 to 1996:4. The model's specification, estimation, validation and application processes are described in Vere *et al.* (2000) and Vere and Griffith (2004).

Structural econometric models have been previously used in association with other types of models to evaluate new technology adoption in Australian sheep production. Griffith *et al.* (1995) used a quarterly structural model of the Australian lamb industry to evaluate the industry benefits from the introduction of new technology for producing large, lean lamb. That evaluation assessed how current lamb production systems and the Australian lamb markets might change with the introduction of the technology. The rationale for using a structural industry model was that if there was a significant level of adoption of the technology in the industry, there would be increases in lamb supply and demand and that would reduce lamb producer prices because of the highly competitive nature of the Australian lamb market. This model enabled the farm-level responses to the technology that were determined using a production systems model, to be aggregated under an assumed industry adoption level to derive measures of total benefits and costs using assumptions about the nature of the lamb industry's supply and demand curves, the type of supply shift, and the relationship between producer and consumer prices. Following those procedures, it was estimated that the technology had the potential to deliver annual benefits to both Australian lamb producers and lamb consumers of between $12 million to $35.5 million according to various market scenarios for the selling the lamb product on the domestic and export markets.

Appendix B: Costs of the Sheep CRC used in the Economic Evaluations

Table B1. Sheep CRC program costs and value of in-kind contributions ($'000)

	2001-02		2002-03		2003-04		2004-05		2005-06[a]		2006-07[b]		2007-08[b]	
Projects	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**
1.1.1		91.02	104.53	282.84	141.51	861.64	242.88	527.88	105.23	316.05	105.23	316.05	105.23	316.05
1.1.2		23.29	19.27	116.33	47.41	160.47	25.00	143.07	19.73	79.35	19.73	79.35	19.73	79.35
1.1.3		26.60	57.35	117.77	55.81	254.57	20.00	135.337	28.66	95.94	28.66	95.94	28.66	95.94
1.1.4	37.06	55.93	109.90	256.37	175.63	331.18	97.67	382.23	90.45	183.27	90.45	183.27	90.45	183.27
1.1.5		27.96	63.04	140.24	175.84	131.47	90.00	202.07	70.78	89.54	70.78	89.54	70.78	89.54
1.1.6		18.32			31.63	117.18	60.38	162.87	19.80	52.93	19.80	52.93	19.80	52.93
1.1.9	5.00	7.93	15.73	32.18	8.51		15.50	79.76	9.63	21.16	9.63	21.16	9.63	21.16
1.2.1		18.71			35.19	123.45	80.60	176.04	24.92	56.60	24.92	56.60	24.92	56.60
1.2.2	46.06	41.15	97.01	466.23	118.03	228.50	113.40	175.52	80.60	164.46	80.60	164.46	80.60	164.46
1.2.3		36.93			117.66	296.06	70.09	321.15	40.41	116.64	40.41	116.64	40.41	116.64
1.2.4		16.01					105.25	203.39	22.65	38.44	22.65	38.44	22.65	38.44
1.2.5		83.69	194.56	579.27	413.24	680.52	142.00	433.39	161.37	319.98	161.37	319.98	161.37	319.98
1.2.6		55.03					424.21	699.21	91.30	132.14	91.30	132.14	91.30	132.14
1.2.9	5.00	7.92	20.77	55.81	90.48	145.35	45.00		34.70	38.02	34.70	38.02	34.70	38.02

Table B1 (cont.). Sheep CRC program costs and value of in-kind contributions ($'000)

	2001-02		2002-03		2003-04		2004-05		2005-06[a]		2006-07[b]		2007-08[b]	
Projects	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**
1.3.1A		38.20		235.01			131.77	369.72	28.36	114.29	28.36	114.29	28.36	114.29
1.3.1B		34.99		94.01			127.00	399.37	27.33	93.24	27.33	93.24	27.33	93.24
1.3.1C		21.70		118.14			93.38	217.68	20.10	63.47	20.10	63.47	20.10	63.47
1.3.1D		25.51		192.65			135.00	229.04	29.05	79.69	29.05	79.69	29.05	79.69
1.3.1	1.54	35.90	411.05		526.96	915.66			202.21	173.05	202.21	173.05	202.21	173.05
1.3.2		11.29	2.32	49.67	49.60	43.88	50.00	97.17	21.93	36.04	21.93	36.04	21.93	36.04
1.3.4		4.857	25.64	80.49			50.00	21.69	16.27	19.31	16.27	19.31	16.27	19.31
1.3.5		87.68	104.06	268.72	278.17	470.07	311.00	748.83	149.19	281.13	149.19	281.13	149.19	281.13

1.3.6		13.57	78.88	22.82	175.29	195.99	291.35	63.72	117.41	53.39	117.41	53.39	117.41	53.39
1.3.9	1.07	4.95	35.17	52.01	75.30		58.80	37.15	36.66	16.85	36.66	16.85	36.66	16.85
1.4.1 A		46.99	67.07	255.21	110.81	215.54	103.00	367.56	60.45	158.43	60.45	158.43	60.45	158.43
1.4.1 B		26.12			90.86	211.41	79.00	229.36	36.56	83.29	36.56	83.29	36.56	83.29
1.4.1 C		17.37			24.18	185.67	110.00	130.06	28.86	59.67	28.86	59.67	28.86	59.67
1.4.1 D		22.68			75.39	187.59	53.00	197.16	27.63	72.71	27.63	72.71	27.63	72.71
1.4.1 E														
1.4.2 A		32.52	67.02	113.91	121.63	175.85	60.00	272.33	53.52	106.23	53.52	106.23	53.52	106.23
1.4.2 B		41.53			166.70	307.58	156.00	379.02	69.45	129.76	69.45	129.76	69.45	129.76
1.4.3		65.30	18.93	240.60	211.65	401.61	283.00	516.61	110.53	218.99	110.53	218.99	110.53	218.99
1.4.4		17.78		26.87	117.41	182.54	30.00	123.45	31.72	62.90	31.72	62.90	31.72	62.90
1.4.5		19.27		30.27	27.39	193.14	163.50	135.48	41.08	67.87	41.08	67.87	41.08	67.87
1.4.9	5.00	12.09	12.35	102.64	16.67	88.97	30.00	59.31	13.78	47.42	13.78	47.42	13.78	47.42

Table B1 (cont.). Sheep CRC program costs and value of in-kind contributions ($'000)

	2001-02		2002-03		2003-04		2004-05		2005-06[a]		2006-07[b]		2007-08[b]	
Projects	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**	**Sheep CRC**	**In-kind**
1.5.1		59.63	93.88	138.51	156.33	362.11	144.00	480.01	84.84	185.32	84.84	185.32	84.84	185.32
1.5.2		35.68			86.88	334.65	70.00	269.68	33.76	114.21	33.76	114.21	33.76	114.21
1.5.3		51.56			103.52	342.65	159.00	460.26	56.50	151.74	56.50	151.74	56.50	151.74
1.5.4		4.89			7.75	119.99			1.67	22.68	1.67	22.68	1.67	22.68
1.5.5		106.96	78.87	576.59	220.12	939.68	155.00	552.00	97.71	390.87	97.71	390.87	97.71	390.87
1.5.9		4.55			5.69	39.75	18.00	35.90	5.09	14.30	5.09	14.30	5.09	14.30
2.1.1		2.43	35.21	127.98	50.94	324.40			18.54	72.44	18.54	72.44	18.54	72.44
2.1.2		6.09	24.73	69.49	81.77	238.47	131.00	411.98	51.13	115.28	51.13	115.28	51.13	115.28
2.1.3		2.91			94.99	541.87			20.44	86.77	20.44	86.77	20.44	86.77
2.2.1		1.87	51.89	97.64	79.97	80.09	80.00	85.02	45.60	42.07	45.60	42.07	45.60	42.07
2.2.2		3.08	7.06	170.50	27.41	172.93		114.97	7.42	73.40	7.42	73.40	7.42	73.40
2.2.3		5.52			287.85	609.47	71.00	208.63	77.23	130.99	77.23	130.99	77.23	130.99
2.2.4		1.13					44.00	104.99	9.47	16.81	9.47	16.81	9.47	16.81
2.3.1		6.44	55.73	158.21	186.63	296.25	150.00	371.73	84.44	132.29	84.44	132.29	84.44	132.29
2.3.2		8.58	4.10	129.27	209.78	391.98	255.00	537.11	100.91	169.47	100.91	169.47	100.91	169.47
2.9.1	6.61	2.45	0.13	59.95	33.55	100.26	42.00	147.78	17.71	49.32	17.71	49.32	17.71	49.32

Table B1 (cont.). Sheep CRC program costs and value of in-kind contributions: summary ($'000)

	2001-02		2002-03		2003-04		2004-05		2005-06		Annual costs 2006-07 to 2007-08	
Programs	**CRC costs**	**In-kind**	**CRC costs**	**In-kind**	**CRC costs**	**In-kind**	**CRC costs**	**In-kind**	**CRC costs**	**In-kind**	**CRC costs**	**In-kind**
Sub-total 1.1	42.06	251.04	369.83	945.73	636.34	1,856.52	551.44	1,633.20	344.28	838.23	344.28	838.23
Sub-total 1.2	51.06	259.44	312.34	1,101.31	774.60	1,473.87	980.55	2,008.70	455.95	866.28	455.95	866.28
Sub-total 1.3	2.61	278.66	657.13	1,113.51	1,105.32	1,625.60	1,248.31	2,184.37	648.53	930.46	648.53	930.46
Sub-total 1.4	5.00	301.65	165.38	769.50	962.63	2,149.90	1,067.50	2,410.34	473.59	1,007.23	473.59	1,007.23

Sub-total 1.5		263.28	172.74	715.10	580.30	2,138.83	546.00	1,797.87	279.58	879.11	279.58	879.11
Total program 1	100.74	1,354.06	1,677.41	4,645.16	4,059.19	9,244.72	4,393.80	10,034.48	2,201.92	4,521.31	2,201.92	4,521.31
Total program 2	6.61	40.51	178.86	813.03	1,052.87	2,755.72	773.00	1,982.21	432.87	888.84	432.87	888.84
Total program 3	75.85	129.47	282.92	625.16	409.99	886.46	467.00	927.63	265.96	546.10	265.96	546.10
Total program 4	2.01	94.21	124.87	563.41	816.63	894.33	2,029.18	2,427.27	639.77	1,313.68	639.77	1,313.68
Total program 5	194.89	293.76	608.97	144.25	727.89	206.80	675.00		474.93	975.20	474.93	975.20
Program total	380.09	1,912.00	2,873.03	6,791.00	7,066.57	13,988.03	8,337.97	15,371.59	4,015.45	8,245.13	4,015.45	8,245.13
Total Sheep CRC costs 2001-2008			30,121.25									
Total in-kind costs 2001-2008			61,601.35									

Table B2(a). *With*-Sheep CRC research Programs 1 and 2 cost summary ($'000)

	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
Wool research costs							
Genetics	191.68	860.34	1,609.46	1,410.67	881.34	926.47	649.22
Wool science	240.77	1,096.20	1,653.45	2,279.93	1,437.62	1,269.66	918.30
Parasites	174.76	532.79	1,773.82	1,951.58	1,056.36	845.22	683.15
Nutrition	49.2	165.9	502.65	427.75	262.93	257.9	67.54
IAM	21.57	49.97	1,719.41	1,225.91	1,049.06	1,017.84	747.65
Wool extension costs							
Genetics	0	0	20.81	18.03	10.54	12.92	11.74
Wool science	0	0	90.10	38.01	106.43	48.36	44.01
Parasites	0	0	0	30.42	60.57	198.16	78.97
Nutrition	0	0	5.42	10.20	6.54	9.50	2.89
IAM	0	4.09	24.10	35.39	44.48	55.20	50.26
Meat research costs							
Genetics	82.15	368.72	689.77	604.57	377.72	397.06	278.24
Wool science	49.31	224.52	338.66	466.98	294.45	260.05	188.11
Meat science	262.78	1,654.41	2,499.74	3,090.37	1,715.04	1,695.05	1,301.60
Parasites	111.73	340.63	1,134.08	1,247.73	675.37	540.39	436.77
Nutrition	196.77	663.57	2,010.60	1,711.01	1,051.71	1,031.59	270.14
IAM	22.45	468.34	1,789.59	1,275.95	1,091.88	1,059.38	778.17
Meat extension costs							
Genetics	0	0	8.92	7.73	4.52	5.54	5.04
Wool science	0	0	18.45	7.78	21.80	9.90	9.02
Meat science	0	0	51.64	116.62	70.84	108.55	32.93
Parasites	0	0	0	19.45	38.72	126.69	50.49
Nutrition	0	0	21.68	40.81	26.16	38.00	11.53
IAM	0	4.26	25.08	36.83	46.30	57.47	52.32

Table B2(b). *Without*-Sheep CRC research cost summary ($'000)

	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
Wool research costs							
Genetics	131.34	494.79	971.30	854.46	544.83	544.83	340.95
Wool science	160.93	683.19	914.31	1,246.09	667.62	667.62	417.79
Parasites	137.53	350.83	980.17	1,098.91	570.49	570.49	357.01
Nutrition	39.35	106.90	319.71	268.75	163.25	163.25	10.22
IAM	14.84	297.76	1,009.22	725.94	637.60	637.60	437.28
Meat research costs							
Genetics	56.29	212.06	416.27	366.20	233.50	233.50	146.12
Wool science	32.96	139.93	187.27	255.22	136.74	137.02	85.57
Meat science (supply)	104.13	416.13	607.49	816.30	431.98	431.98	270.33
Meat science (demand)	104.13	416.13	607.49	816.30	431.98	431.98	270.33
Parasites	6.76	17.26	48.21	54.05	28.06	28.06	16.62
Nutrition	157.42	427.57	1,278.85	1,074.99	653.02	653.02	40.86
IAM	15.44	309.91	1,050.41	755.57	663.63	663.63	455.12

Appendix C: Stochastic Simulation Model for Calculating Economic Surplus Changes and Benefit-Cost Outcomes for Sheep CRC Evaluations: *With-* and *Without-*Sheep CRC Scenarios

MODEL FOR PROJECT 1.1.1 - Genetic Analysis of Sheep Production Traits

Input data

```
source("C:/DATA/WPDOCS/CRCSHEEP/SSMODEL/rtriangle.r")
source("C:/DATA/WPDOCS/CRCSHEEP/SSMODEL/bca.r")
# Number of iterations for simulation
NSim <- 10000
```

Define regions

```
AUSWL   - wool Australia
CHWL    - wool China
EUWL    - wool European Union
NZWL    - wool New Zealand
ROWWL   - wool rest of World
AUSSM   - sheepmeat Australia
CHSM    - sheepmeat China
EUSM    - sheepmeat European Union
NZSM    - sheepmeat New Zealand
ROWSL   - sheepmeat rest of World
```

Wool supply

```
SWAUS    <- 669000  # wool production, Australia (t)
SWCHIN  <- 280700  # wool production, China (t)
SWEU      <- 176700  # wool production, EU (t)
SWNZ      <- 255700  # wool production, New Zealand (t)
SWROW   <- 1016300 # wool production, ROW (t)
```

Wool demand

```
DWAUS    <- 17900   # wool consumption, Australia (t)
DWCHIN  <- 328700  # wool consumption, China (t)
DWEU      <- 345800  # wool consumption, EU (t)
DWNZ      <- 23300   # wool consumption, New Zealand (t)
DWROW  <- 1682700 # wool consumption, ROW (t)
```

Meat supply

```
SMAUS      <- 617200  # sheepmeat production, Australia (t)
SSMCHIN  <- 1715100 # sheepmeat production, China (t)
SSMEU      <- 1480300 # sheepmeat production, EU (t)
SSMNZ      <- 530600  # sheepmeat production, New Zealand (t)
SSMROW  <- 3090100 # sheepmeat production, ROW (t)
```

Meat demand

```
DSMAUS    <- 312400  # sheepmeat consumption, Australia (t)
DSMCHIN  <- 2223500 # sheepmeat consumption, China (t)
DSMEU      <- 1900600 # sheepmeat consumption, EU (t)
DSMNZ      <- 69300   # sheepmeat consumption, New Zealand (t)
DSMROW   <- 2927500 # sheepmeat consumption, ROW (t)
```

Prices

```
Wprice <- 7000 # average price of greasy wool in Australia $/t equivalent; vary by 20%
wool price triangular distribution values (min, median, max)
tP <- cbind(5600, 7000, 8400)
Wprice <- rtriangle(n=NSim, min=tP[1], mode=tP[2], max=tP[3])

SMprice <- 3273.2 # price of sheepmeats in Australia $/t equivalent; same weighted average price
as used in the DREAM modelling)
sheepmeat price triangular distribution values (min, median, max)
tP <- cbind(2618.6, 3273.2, 3927.8)
Mprice <- rtriangle(n=NSim, min=tP[1], mode=tP[2], max=tP[3])
```

Elasticities medium term values (0.5 = default value)

```
eWAUS   <- 0.45  # wool supply elasticity, Australia
eWCHIN <- 0.25  # wool supply elasticity, China
eWEU     <- 0.5   # wool supply elasticity, EU
eWNZ     <- 0.33  # wool supply elasticity, NZ
eWROW <- 1.0   # wool supply elasticity, ROW

nWAUS   <- 0.8   # wool demand elasticity, Australia
nWCHIN <- 0.33  # wool demand elasticity, China
nWEU      <- 0.24  # wool demand elasticity, EU
nWNZ      <- 1.11  # wool demand elasticity, NZ
nWROW  <- 0.35  # wool demand elasticity, ROW

eSMAUS   <- 1.38 # sheepmeat supply elasticity, Australia
eSMCHIN <- 0.3  # sheepmeat supply elasticity, China
eSMEU     <- 0.67 # sheepmeat supply elasticity, EU
eSMNZ    <- 0.50 # sheepmeat supply elasticity, NZ
eSMROW  <- 0.50 # sheepmeat supply elasticity, ROW

nSMAUS   <- 0.49 # sheepmeat demand elasticity, Australia
nSMCHIN <- 0.45 # sheepmeat demand elasticity, China
nSMEU     <- 0.92 # sheepmeat demand elasticity, EU
nSMNZ     <- 0.6  # sheepmeat demand elasticity, NZ
nSMROW  <- 0.5  # sheepmeat demand elasticity, ROW
```

Specify K shifts triangular distribution values (min, median, max); vary +/- 20%

```
tWAUSK  <- cbind(0.0016, 0.002, 0.0024) # Australian wool supply shift
WAUSK  <- rtriangle(n=NSim, min=tWAUSK[1], median=tWAUSK[2], max=tWAUSK[3])

tSMAUSK  <- cbind(0.0024, 0.003, 0.0036) # Australian sheepmeat supply shift
SMAUSK   <- rtriangle(n=NSim, min=tSMAUSK[1], median=tSMAUSK[2], max=tSMAUSK[3])
```

Calculate Z values

```
Australian wool Z
WAUSZ <- eWAUS*WAUSK/(eWAUS+nWAUS)

Australian sheepmeat Z
SMAUSZ <- eSMAUS*SMAUSK/(eSMAUS+nSMAUS)
```

ECONOMIC SURPLUS CHANGE FORMULAE

Wool - producer surplus and consumer surplus calculations: open economy with world trade spillovers

```
dWPSAUS    <-  SWAUS*Wprice*(WAUSK-WAUSZ)*(1+0.5*WAUSZ*eWAUS)/1000000
dWPSCHIN  <- -SWCHIN*Wprice*WAUSZ*(1+0.5*WAUSZ*eWCHIN)/1000000
dWPSEU     <- -SWEU*Wprice*WAUSZ*(1+0.5*WAUSZ*eWEU)/1000000
dWPSNZ     <- -SWNZ*Wprice*WAUSZ*(1+0.5*WAUSZ*eWNZ)/1000000
dWPSROW  <- -SWROW*Wprice*WAUSZ*(1+0.5*WAUSZ*eWROW)/1000000

dWCSAUS    <-  DWAUS*Wprice*WAUSZ*(1+0.5*WAUSZ*nWAUS)/1000000
dWCSCHIN  <-  DWCHIN*Wprice*WAUSZ*(1+0.5*WAUSZ*nWCHIN)/1000000
dWCSEU     <-  DWEU*Wprice*WAUSZ*(1+0.5*WAUSZ*nWEU)/1000000
dWCSNZ     <-  DWNZ*Wprice*WAUSZ*(1+0.5*WAUSZ*nWNZ)/1000000
dWCSROW  <-  DWROW*Wprice*WAUSZ*(1+0.5*WAUSZ*nWROW)/1000000
```

Total economic surplus change for wool

```
dTSSTWL  <- matrix(ncol=1,nrow=NSim)
dTSSTWL  <- dWPSAUS + dWPSCHIN + dWPSEU + dWPSNZ + dWPSROW + dWCSAUS
+ dWCSCHIN + dWCSEU + dWCSNZ + dWCSROW
```

Sheepmeat - producer surplus and consumer surplus calculations: open economy with world trade spillovers

```
dSMPSAUS    <-  SMAUS*SMprice*(SMAUSK-SMAUSZ)*(1+0.5*SMAUSZ*eSMAUS)/1000000
dSMPSCHIN  <- -SMCHIN*SMprice*SMAUSZ*(1+0.5*SMAUSZ*eSMCHIN)/1000000
dSMPSEU      <- -SMEU*SMprice*SMAUSZ*(1+0.5*SMAUSZ*eSMEU)/1000000
dSMPSNZ      <- -SSMNZ*SMprice*SMAUSZ*(1+0.5*SMAUSZ*eSMNZ)/1000000
dSMPSROW   <- -SSMROW*SMprice*SMAUSZ*(1+0.5*SMAUSZ*eSMROW)/1000000

dSMCSAUS    <-  DSMAUS*SMprice*SMAUSZ*(1+0.5*SMAUSZ*nSMAUS)/1000000
dSMCSCHIN  <-  DSMCHIN*SMprice*SMAUSZ*(1+0.5*SMAUSZ*nSMCHIN)/1000000
dSMCSEU      <-  DSMEU*SMprice*SMAUSZ*(1+0.5*SMAUSZ*nSMEU)/1000000
dSMCSNZ      <-  DSMNZ*SMprice*SMAUSZ*(1+0.5*SMAUSZ*nSMNZ)/1000000
dSMCSROW  <-  DSMROW*SMprice*SMAUSZ*(1+0.5*SMAUSZ*nSMROW)/1000000
```

Total economic surplus change for sheepmeat

```
dTSSTSM  <- matrix(ncol=1,nrow=NSim)
dTSSTSM <- dSMPSAUS + dSMPSCHIN + dSMPSEU + dSMPSNZ + dSMPSROW + dSMCSAUS
+ dSMCSCHIN + dSMCSEU + dSMCSNZ + dSMCSROW
```

Total economic surplus change: all regions and products

```
dTSST <- matrix(ncol=1,nrow=NSim)
dTSST <- dTSSTWL+dTSSTSM
```

Create summary statistics - means, SD, maximums and minimums for economic surplus changes

Wool

```
meansWL <- cbind(meanWPSAUS, meanWPSCHIN, meanWPSEU, meanWPSNZ, meanWPSROW,
meanWCSAUS, meanWCSCHIN, meanWCSEU, meanWCSNZ, meanWCSROW)

maxsWL <- cbind(maxWPSAUS, maxWPSCHIN, maxWPSEU, maxWPSNZ, maxWPSROW,
maxWCSAUS, maxWCSCHIN, maxWCSEU, maxWCSNZ, maxWCSROW)

minsWL <- cbind(minWPSAUS, minWPSCHIN, minWPSEU, minWPSNZ, minWPSROW,
minWCSAUS, minWCSCHIN, minWCSEU, minWCSNZ, minWCSROW)
```

Sheepmeats
meansSM <- cbind(meanSMPSAUS, meanSMPSCHIN, meanSMPSEU, meanSMPSNZ, meanSMPSROW,
meanSMCSAUS, meanSMCSCHIN, meanSMCSEU, meanSMCSNZ, meanSMCSROW)

maxsSM <- cbind(maxSMPSAUS, maxSMPSCHIN, maxSMPSEU, maxSMPSNZ, maxSMPSROW,
maxSMCSAUS, maxSMCSCHIN, maxSMCSEU, maxSMCSNZ, maxSMCSROW)

minsSM <- cbind(minSMPSAUS, minSMPSCHIN, minSMPSEU, minSMPSNZ, minSMPSROW,
minSMCSAUS, minSMCSCHIN, minSMCSEU, minSMCSNZ, minSMCSROW)

These commands calculate the summary statistics for the economic surplus changes

Wool
TmeanESWL <- rbind(mean(dTSSTWL))
TmaxESWL <- rbind(max(dTSSTWL))
TminESWL <- rbind(min(dTSSTWL))
statsESWL <- cbind(TmeanESWL, TmaxESWL, TminESWL)

Sheepmeat
TmeanESSM <- rbind(mean(dTSSTSM))
TmaxESSM <- rbind(max(dTSSTSM))
TminESSM <- rbind(min(dTSSTSM))
statsESSM <- cbind(TmeanESSM, TmaxESSM, TminESSM)

Total economic surplus change
TmeanTSST <- rbind(mean(dTSST))
TmaxTSST <- rbind(max(dTSST))
TminTSST <- rbind(min(dTSST))
statsTSST <- cbind(TmeanTSST, TmaxTSST, TminTSST)

SET UP BENEFIT-COST ANALYSIS; use the total surplus estimates as annual measures of benefit for each scenario; this will apply the probability distributions to the benefit estimates based on the ranges defined in the triangular function. This model distinguishes between the with and without research scenarios; difference = different R&D and adoption lag assumptions that impact on the discounting.

BCA specifications
number of years in BCA
NYear <- 20

Define the discount rate
drate <- 0.05

Define the BCA procedure
time <- (1:NYear)

Define discount factor
dfactor <- matrix(data=(1/(1+drate)^time), nrow=NSim, ncol=NYear, byrow=T)

Define adoption scenarios
Values from Rendell-McGuckian model are the means; varied by 20% each way (cover both wool and meat)

***With*- Sheep CRC**

Adoption for with Sheep CRC has shorter lags and higher adoption ceiling
Define adoption rates - AW = adoption, CW = ceiling, LW = total R&D and adoption lag

```
CWrisk <- cbind(0.39, 0.49, 0.59) # triang distribution for ceiling adoption
LWrisk <- cbind(5.6, 7.0, 8.4) # triang dist for adoption lag
AW <- matrix(data=0, nrow=NSim, ncol=NYear)
CW <- rtriangle(n=NSim, min=CWrisk[1], median=CWrisk[2], max=CWrisk[3])
LW <- rtriangle(n=NSim, min=LWrisk[1], median=LWrisk[2], max=LWrisk[3])
LW <- trunc(LW)  # this converts real values to integers

for (i in 1:NSim) {
        for (j in 1:NYear) {
                {if(j < LW[i])    AW[i,j] <- 0 }
                {if(j == LW[i])  AW[i,j] <- 0.05 }
                {if(j > LW[i]) AW[i,j] <- AW[i,j-1]+(AW[i,j-1]*(C[i]-AW[i,j-1])) }
        } # ends the j for loop
} # ends the i for loop
```

***Without*- Sheep CRC**

Adoption for without Sheep CRC has longer lags and lower adoption ceiling
Define adoption rates - AWO = adoption, CWO = ceiling, LWO = total R&D and adoption lag

```
CWOrisk <- cbind(0.26, 0.32, 0.38) # triang distribution for ceiling adoption
LWOrisk <- cbind(10.6, 12.0, 13.4) # triang dist for adoption lag
AWO <- matrix(data=0, nrow=NSim, ncol=NYear)
CWO <- rtriangle(n=NSim, min=CWOrisk[1], median=CWOrisk[2], max=CWOrisk[3])
LWO <- rtriangle(n=NSim, min=LWOrisk[1], median=LWOrisk[2], max=LWOrisk[3])
LWO <- trunc(LWO)  # this converts real values to integers

for (i in 1:NSim) {
        for (j in 1:NYear) {
                {if(j < LWO[i]) AWO[i,j] <- 0 }
                {if(j == LWO[i]) AWO[i,j] <- 0.05 }
                {if(j > LWO[i]) AWO[i,j] <- AWO[i,j-1]+(AWO[i,j-1]*(C[i]-AWO[i,j-1])) }
        } # ends the j for loop
} # ends the i for loop
```

Define program/project costs ($million)

***With*- Sheep CRC costs Program 1.1.1** (research + extension)

```
TWCost1  <- 0.09102
TWCost2  <- 0.38737
TWCost3  <- 1.00315
TWCost4  <- 0.77076
TWCost5  <- 0.76141
TWCost6  <- 0.80194
TWCost7  <- 0.56397

TWCosts <- matrix(data=XTWCost, nrow=NSim, ncol=NYear, byrow=t)
TWCosts[,1] <- TWCosts[,1] + TWCost1
TWCosts[,2] <- TWCosts[,2] + TWCost2
TWCosts[,3] <- TWCosts[,3] + TWCost3
TWCosts[,4] <- TWCosts[,4] + TWCost4
TWCosts[,5] <- TWCosts[,5] + TWCost5
TWCosts[,6] <- TWCosts[,6] + TWCost6
TWCosts[,7] <- TWCosts[,7] + TWCost7
```

***Without*- Sheep CRC costs** (assume to be 80% of CRC in kind costs)

```
TWOCost1  <- 0.068265
TWOCost2  <- 0.290527
TWOCost3  <- 0.752363
TWOCost4  <- 0.57807
TWOCost5  <- 0.57106
TWOCost6  <- 0.601455
TWOCost7  <- 0.422978

TWOCosts <- matrix(data=XTWOCost,nrow=NSim, ncol=NYear, byrow=t)
TWOCosts[,1] <- TWOCosts[,1] + TWOCost1
TWOCosts[,2] <- TWOCosts[,2] + TWOCost2
TWOCosts[,3] <- TWOCosts[,3] + TWOCost3
TWOCosts[,4] <- TWOCosts[,4] + TWOCost4
TWOCosts[,5] <- TWOCosts[,5] + TWOCost5
TWOCosts[,6] <- TWOCosts[,6] + TWOCost6
TWOCosts[,7] <- TWOCosts[,7] + TWOCost7
```

BENEFIT-COST ANALYSIS PROJECT 1.1.1

***With*- Sheep CRC**; discount annual benefits

```
mycalc <- bca (amount=dTSST, df=dfactor, adopt=AW, cost=TWCosts)
npvW <- mycalc$npv
bcrW <- mycalc$bcr
```

***Without*- Sheep CRC**; discount annual benefits

```
mycalc <- bca (amount=dTSST, df=dfactor, adopt=AWO, cost=TWOCosts)
npvWO <- mycalc$npv
bcrWO <- mycalc$bcr
```

These commands calculate the summary statistics for the BCA results

***With*- Sheep CRC**

```
meanNPVW <- rbind(mean(npvW))
minNPVW <- rbind(min(npvW))
maxNPVW <- rbind(max(npvW))
statsNPVW <- cbind(meanNPVW, minNPVW, maxNPVW)

meanBCRW <- rbind(mean(bcrW))
minBCRW <- rbind(min(bcrW))
maxBCRW <- rbind(max(bcrW))
statsBCRW <- cbind(meanBCRW, minBCRW, maxBCRW)

probs <- seq(0.0, 1.0, 0.05)
```

Calculate percentiles for NPV CDF

```
cdf <- c(quantile(npvW,prob=probs))
CDFnpvW <- data.frame(cdf)
```

Calculate percentiles for BCR CDF

```
cdf <- c(quantile(bcrW,prob=probs))
CDFbcrW <- data.frame(cdf)
```

***Without*- Sheep CRC**

```
meanNPVWO <- rbind(mean(npvWO))
minNPVWO <- rbind(min(npvWO))
maxNPVWO <- rbind(max(npvWO))
statsNPVWO <- cbind(meanNPVWO, minNPVWO, maxNPVWO)

meanBCRWO <- rbind(mean(bcrWO))
minBCRWO <- rbind(min(bcrWO))
maxBCRWO <- rbind(max(bcrWO))
statsBCRWO <- cbind(meanBCRWO, minBCRWO, maxBCRWO)

probs <- seq(0.0, 1.0, 0.05)
```

Calculate percentiles for NPV CDF

```
cdf <- c(quantile(npvWO,prob=probs))
CDFnpvWO <- data.frame(cdf)
```

Calculate percentiles for BCR CDF

```
cdf <- c(quantile(bcrWO,prob=probs))
CDFbcrWO <- data.frame(cdf)
```

Value of the *with*- Sheep CRC scenario = NPV differences between the scenarios

```
dnpvWCRC <- npvW-npvWO

dmeanNPVWCRC <- rbind(mean(dnpvWCRC))
dminNPVWCRC <- rbind(min(dnpvWCRC))
dmaxNPVWCRC <- rbind(max(dnpvWCRC))
statsdNPVWCRC <- cbind(dmeanNPVWCRC, dminNPVWCRC, dmaxNPVWCRC)

probs <- seq(0.0, 1.0, 0.05)
```

Calculate percentiles for NPV CDF

```
cdf <- c(quantile(dnpvWCRC,prob=probs))
CDFdnpvWCRC <- data.frame(cdf)
```

= NPV differences between the scenarios

```
dbcrWCRC <- bcrW-bcrWO

dmeanBCRWCRC <- rbind(mean(dbcrWCRC))
dminBCRWCRC <- rbind(min(dbcrWCRC))
dmaxBCRWCRC <- rbind(max(dbcrWCRC))
statsdBCRWCRC <- cbind(dmeanBCRWCRC, dminBCRWCRC, dmaxBCRWCRC)

probs <- seq(0.0, 1.0, 0.05)
```

Calculate percentiles for NPV CDF

```
cdf <- c(quantile(dbcrWCRC,prob=probs))
CDFdbcrWCRC <- data.frame(cdf)
```

End

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